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QUASI-MONOCHROMATIC VISUAL ENVIRONMENTS AND THE RESTING POINT OF ACCOMMODATION

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This investigation explored the importance of color as a factor in deterioration of correct visual accommodation and involuntary regression to the resting point of accommodation. The involvement of voluntary control of accommodation processes was manipulated by requiring extended performance on a difficult visual task. Broad band red and green as well as white visual environments were presented in two related experiments. The first considered color, light level and time on task. The second attempted a more specific examination of color and time on task. Expected light level, time on task and chromatic aberration effects were evident. Declining light levels and extended time on task produced expected decrements in accommodation. Ambient color environments produced predictable differential accommodation. No statistically significant differences were revealed to support the possibility of color mediated differential regression to resting point of accommodation.

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EXECUTIVE SUMMARY

PROBLEM

Visually oriented tasks are ever present and increasingly important in virtually all human performance situations. The range of requirements in military situations spans the role of the junior watch stander to that of the most senior commander. Visual acuity is of central importance for these tasks and is directly related to individual ability to maintain accurate accommodation.

OBJECTIVE

The present effort was conducted as doctoral dissertation research by Lieutenant Commander Edward Trautman while in out-service training at the University of South Dakota. It's purpose was to explore the importance of ambient color for maintenance of visual accommodation.

APPROACH

Correct accommodation and regression toward the resting point of accommodation were considered in achromatic and quasimonochromatic light environments. The involvement of voluntary control in accommodation processes was manipulated by requiring extended performance on a difficult visual task. Broad band red and green, as well as white, environments were presented in two related experiments. The first considered color, light level and time on task. The second attempted a more specific examination of color and time on task.

FINDINGS

Expected light level, time on task and chromatic aberration effects were evident. Declining light levels and extended time on task produced expected decrements in accommodation. Ambient color environments produced predictable differential accommodation. These results strongly supported the validity of the experimental approach. Interactions which would have indicated color mediated, differential regression toward resting point accommodation were not apparent.

CONCLUSION

Regression to the resting point of accommodation is not a color mediated phenomenon.

RECOMMENDATIONS

Results of these and other related investigations indicate that the human eye maintains accommodation equally well across a variety of color conditions. Ambient color of the task environment does not appear to be a design concern with respect to maintenance of optimal visual accommodation.

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INTRODUCTION

Understanding the characteristics of human visual accommodation is of considerable interest for those involved in designing for optimal operator performance. Deficiencies which are not obvious from conventional optometric assessment are of particular concern. This project addressed one such topic: the activity of the eye in unstimulated and poorly stimulated visual environments.

Investigations following the advent of the laser optometer have pursued this concern and convincingly argued against the long held assumption that the human eye rests focused at infinity (Simonelli, 1979a; Owens, 1984a, 1984b). Numerous researchers have concluded that the mean resting position of accommodation (RPA) is, in fact, typically less than one meter (Johnson, 1976; Leibowitz & Owens, 1975a, 1978; Miller, Pigion, R., Wesner, M., & Patterson, J. 1983). This new insight offers an explanation for long recognized anomalous myopias, which seem to coincide with specific stimulus environments (e.g. darkened, empty or featureless visual fields). The onset of myopia in such situations corresponds to the shift from accurate accommodation to RPA. Many researchers have considered the implications of this phenomenon for distant viewing tasks. More generally, RPA seems to be implicated in a variety of tasks which require accurate accommodation. Understanding the phenomenon may reveal predictable performance deficiencies. A more comprehensive appreciation for accommodation in task environments which require both near and distant visual performance would be of value for many design applications.

Attention to RPA in work station design could reduce vigilance degradation, improve visual acuity and maximize performance. The following introduction will briefly discuss accommodation and review relevant research regarding the topic of RPA. The research project was intended to further our understanding of RPA and its importance for visual performance. This essentially exploratory effort investigated one as yet poorly understood aspect of the phenomenon: the importance of monochromatic light environments and regression to RPA.

HUMAN VISUAL ACCOMMODATION

Light passing into the human eye is refracted by the cornea, the aqueous humour and the crystalline lens. Under proper control, the image is formed on the retina and accurate focus is maintained by the process of accommodation. Young (1801) observed that the lens served as the variable element in the system, refuting earlier speculation that the eye itself changed shape to accommodate a range of target viewing distances. Interestingly, recent research has indicated that very small (but essentially insignificant) changes in the structure of the eye actually occur in situations requiring extreme accommodation (Beauchamp & Mitchell, 1985).

The major element in the overall refractive system is the cornea which contributes more than 40 diopters of fixed refractive power (Tripathi & Tripathi, 1984; Bruce & Green, 1985). In contrast, the lens provides a variable range of refractive power of no more than 17 diopters in children, which declines to 1-2 diopters in older adults (Tripathi & Tripathi, 1984).

Control of accommodation is accomplished by the ciliary muscle which surrounds the lens and attaches to the lens capsule by a network of suspensory fibers. Accommodative power is achieved by contracting the ciliary process in a sphincter action, reducing tension in the suspensory fibers, and permitting the lens to assume its inherent quasi-spherical shape for greater refractive power. Conversely, retraction of the ciliary process results in increased tension in the suspensory fibers which stretches and flattens the lens for lesser dioptic values (Coren, Porac, C., & Ward, L. 1984; Tripathi & Tripathi, 1984). Campbell & Westheimer, (1960) observed 300 millisecond response times for young, normal individuals accompanied by achievement of complete accommodation within 900 milliseconds.

The Trochlear nerve affects control of accommodative processes (Angevine & Cotman, 1981) which have both voluntary and autonomic aspects (Marg, 1951; Randle, 1970). Parasympathetic involvement was once regarded as the source of autonomic control. More recent opinions have suggested the additional involvement of sympathetic input. Dual innervation of autonomic control had been previously established in other smooth muscles, such as the heart and the intestine, and is currently assumed to be the source of ciliary control (Gawron, 1979; Simonelli, 1979a).

Common ametropic deficiencies result when manipulation of the lens fails to provide adequate refraction to compensate for changing target distances or for defects in the structure of the eye. Myopia, for example, describes refractive error in eyes incapable of focusing distant stimuli (i.e., near sightedness). Although permanent myopias are a clinical concern treated with corrective lenses, temporary myopias may also occur in otherwise emmetropic eyes when the visual environment is insufficiently stimulating for normal accommodation. Such inappropriate responses are often discussed as "anomalous myopias".

ANOMALOUS MYOPIAS

There are several well recognized anomalous myopias, including dark, empty field and instrument. Dark myopia occurs in the absence of visual input. Considerable evidence has suggested that less than complete darkness also induces the phenomenon (Koomen, Scolnik, R. & Tousey, R. 1950; Otero, 1951). Conversely, empty field myopia occurs in well lit, even brightly lit, but featureless environments (Westheimer, 1957). Although not frequently experienced, such situations may occur in natural settings. Often discussed examples are reported from pilots who fly in visually homogenous cloud formations and at extremely high altitudes which provide no visual cues. Arctic "white-out" provides yet another example of a featureless environment. Instrument myopia was the first documented and is perhaps the least

intuitively obvious of the temporary myopias. As early as the eighteenth century Maskelyne reported the benefits of optically correcting astronomical telescopes to compensate for the deficiency (Owens, 1984a). Such temporary myopias are also commonly reported with microscopes, which are designed for viewing at visual infinity. Other investigators (Miller, Wesner,M., Pigion, R. & Martins, K. 1984) have considered the effect with the phoropter (i.e., a common optometric device), and found the same deficiency.

In summary, it is generally accepted that anomalous myopias occur in a variety of visual environments. A common characteristic of such environments is the absence or degradation of accommodation cues. Dark myopia results from situations which lack adequate overall illumination. Empty field myopia occurs in illuminated settings which lack the normal richness of environmental cues. Instrument myopia occurs when viewing thru a small diameter aperture simulates constricted natural pupils, provides for maximum depth of field and thereby obviates cues important for maintenance of proper focus. Furthermore, many researchers (Owens & Leibowitz, 1976; Owens, 1979) have suggested that accommodation in cue deprived situations reverts to an individually characteristic resting posture. Thus, the RPA is regarded as the common element for predicting visual performance deficiencies associated with anomalous myopias.

THE RESTING POINT OF ACCOMMODATION

Many temporary myoptic deficiencies are explainable as regression to the resting point of accommodation (Schober, 1954 - cited in Leibowitz & Owens, 1981). The resting point refers to the posture assumed in the absence of effective accommodative stimuli. Owens, explained that:

> "Whenever visual conditions are degraded, the eyes tend to shift involuntarily to the individual's 'resting' distance. That is, owing to the natural tonus of the eye muscles, they adjust to see things at a particular distance. This resting distance varies widely from one person to another, and is often not appropriate for the task at hand." (Owens, 1984a p. 378)

The "natural tonus of the eyes" is a function of the influences of a dual innervation from sympathetic and parasympathetic systems. Sympathetic influences result in decreased accommodation and increased hyperopia. Parasympathetic influences increase both accommodation and consequently myopia (Simonelli, 1979a). The balance achieved in the absence of adequate stimuli is regarded as the resting posture.

Literature in this area is expansive and alternate terms are frequently used in discussion of this phenomenon. "Dark focus" is accurate for many situations but ignores the well documented occurrences in brightly lit environments. "Neutral focus" is a good but not commonly used descriptor. "Resting point of accommodation" is frequently found in the literature and

provides a fairly descriptive compromise of terms. It should, however, be noted that the ciliary system may not actually achieve muscular rest in this posture.

MEASURING RESTING POINT ACCOMMODATION

Direct measurement of RPA is inherently difficult because optometric techniques disturb the resting condition. Traditional methods present stimuli which activate the accommodative process and distort the desired measurement. Early attempts to develop unobtrusive measures included a variety of approaches. Often elaborately instrumented, these efforts generally failed to provide the empirical basis necessary to override the long held assumption (Simonelli, 1979a) that RPA was universally fixed at infinity (Helmholtz, 1909).

Knoll (1966) introduced the laser in combination with the Badal principle to provide a stimulus free measurement device. Hennessy (1970, 1972) and Leibowitz & Hennessy (1975) further perfected and initially used this method for investigation of RPA. More specifically, they suggested that the many advantages of this method include: 1) the ability to achieve rapid, accurate evaluations with no specialized training (i.e., requiring 0.5 - 2.0 minutes to achieve a determination within $\pm .13$ diopters); 2) the capability to present test patterns superimposed over both naturalistic and experimental images; and, 3) the absence of inherent accommodative stimulation from the target test pattern. Overall, the device provided the first relatively economical and efficient method for measuring RPA. A very considerable body of research has resulted from this innovation.

Moses (1971) proposed an alternate device, the polarized vernier optometer, which uses ordinary light. It too is economical, simple and of comparable accuracy to the laser device (Simonelli, 1979b, 1980). Both laser and polarized approaches share the same advantages. Both are realistic for most investigators and acceptable for most laboratory budgets. The laser method has the advantage of popularity and therefore provides an element of commonality with most current research.

CHARACTERISTICS OF RESTING POINT OF ACCOMMODATION

Following more than a decade of active research the general nature of RPA is now fairly well understood. Results from a variety of efforts have defined typical RPA as located at an individually characteristic intermediate position. Similarly a number of authors have reported considerable stability of the phenomenon.

Estimates of typical RPA abound. Leibowitz and Owens, two of the more productive researchers in this field, employed the laser optometer in the most significant early experiments (Amerson, 1980). Their broad approach considered a variety of environments. Four separate experiments were discussed in one early report (Leibowitz & Owens, 1975a). Comparisons were attempted across illumination levels, pupil conditions and motivational states

and a range of RPA values of .37 to 2.89 diopters were obtained in these diverse scenarios. Similarly, they reported results from a survey of undergraduates which indicated a mean dark focus of 1.71 and a range of 0 to 4 diopters.

In a related effort Johnson (1976) considered accommodation for different viewing distances in an experiment which manipulated luminance levels of targets and target backgrounds. Accommodation errors across four light levels were found to be progressively greater with reduced luminance. Subjects under-accommodated for near viewing and over-accommodated for distant viewing, again suggesting a fixed focus corresponding to an intermediate distance.

Others have attempted examination of RPA in more realistic situations. Kintz and Bowker (1982) measured accommodation of individuals reading microfiche and hard-copy displays. As with the above investigations, they found that both tasks resulted in characteristic regression toward inaccurate accommodation. The readers drifted to an intermediate position between correct accommodation for the required display viewing distance and their specific RPA. In a second example, Murch (1982) observed a similar effect and noted that various displays provided for a differential magnitude of accommodative error. Similarly, responses tended toward intermediate positions between RPA and accurate accommodations. Greater refractive errors were observed with CRT displays than with hard-copy display presentations of better resolution quality.

Both laboratory and more practical endeavors point to the same conclusions: RPA is located at some intermediate position, typically near 1.3 diopters or approximately 76 centimeters (Leibowitz & Owens, 1975b; Owen, 1987). Individual RPA's vary tremendously across a range of 4 to 0 diopters, corresponding to 25 centimeters to infinity (Leibowitz & Owens, 1975b; Owens, 1984b, 1987). And, the magnitude of shift toward RPA is inversely related to the stimulus quality of the visual environments (Johnson, 1976; Simonelli, 1979a; Kintz & Bowker, 1982; Murch, 1982).

STABILITY OF RESTING POINT ACCOMMODATION

Numerous investigations have considered the stability of RPA across time. Mershon and Amerson (1980 p. 220) found "hardly any greater change" (i.e., mean changes of .24 diopters and .28 diopters) when they reevaluated part of their sample during the initial session and the remainder a week later. Furthermore, no differences were noted with regard to sex or eye dominance. Overall, they obtained a mean RPA of 1.96 diopters for their first evaluation.

Miller (1978a) considered the possibility of diurnal cycle effects on RPA. Morning and evening measurements were obtained in a survey which repeatedly evaluated subjects across a period of 14-24 days. Test-retest reliability coefficients of .948 and .852 were achieved between morning and evening session measurements, and between first and last session measurements, respectively. They concluded that subjects did not vary greatly, although a mean intrasubject variation of 1.07 diopters was reported. The overall group

mean for RPA was found to be 2.76 diopters. In two separate, somewhat more specific examinations of time of day effects, Amerson (1980, 1983) also found differences between early and late measurements. Unlike Miller, he (Amerson, 1983) concluded from the results of a t-test, that the morning and night RPA mean differences of .5 diopters were significant.

Owens and Higgins (1983) examined long term stability but ignored the potential effects of time of day. They found RPA measurements to be reasonably constant over a one year period. Intrasubject mean differences across the three part study were as great as .66 diopter in early phases but averaged much less in the later phases where a maximum mean difference of only .10 diopters was observed.

The above findings suggest a reasonable level of stability in estimates of RPA (Mershon & Amerson, 1980; Miller, 1978a; Owens & Higgins, 1983), although some variation has been observed relative to time of day (Amerson, 1980, 1983). Prominent among the potentially broad category of factors which might affect the stability of the characteristic are age, stress and fatigue.

It is not surprising that shifts in RPA correspond to the presbyopic changes of near point accommodation. Bentivenga, Owens, J., & Messner, K. (1981) examined an older sample and found a mean RPA of .9 diopter with a corresponding mean near point accommodation of 1.1 diopters. Simonelli (1983) reported similar results which indicated a correspondence between more distant RPA and age. Resting focus demonstrates the same tendency as near point accommodation with progressive shifts to more distant focus as the lens ages.

The ciliary muscle, like any muscle, exhibits fatigue effects. Ramazini (1713) very early suggested that "weakness in vision" resulted from near work. Howe (1916) demonstrated that repeated demands for extreme near viewing produced a temporary recession of the near point accommodation. In a more recent and possibly more practical investigation, Ostberg (1980) observed that air traffic controllers and video display terminal operators demonstrated greater RPA values when retested after normal work periods. Such a finding might be discarded as another manifestation of the previously discussed time of day effect (Miller, 1978a; Amerson, 1980, 1983); however, Owens (1986) found the same effect following a short duration task. Specifically, a significant shift of .6 diopters (from 1.7 to 2.31 diopters) was observed following one hour of ordinary reading (Owens & Wolf-Kelly, 1987). Karns and Mershon (1984) attempted a similar investigation in which subjects viewed a cathode ray tube for two hours. They did not find the previously reported significant shift.

None of this provides a very clear description of visual fatigue. Nor does it provide an indication of the relationship between fatigue, accommodation and the overall body state. Miller, et al. (1983) physically exhausted their subjects by placing them at a demanding task while minimizing accommodative activity in a darkened environment but found no change in accommodation. RPA remained stable although the subjects were otherwise

physically fatigued. Such results suggest that accommodation and visual fatigue are separate from the overall fatigue of the body. Yet stress and emotion seem to exert some influence on RPA.

In a simple but interesting study Leibowitz (1976) conducted a series of measurements on three readily available subjects (i.e. two of his graduate students and his laboratory technician). One of the subjects demonstrated a progressive shift to greater accommodation as he approached his thesis defense. Presumably he was affected by situational anxiety. The other two subjects remained relatively consistent with the exception of the technician who demonstrated an isolated, unexplained shift which spontaneously disappeared after two days. Subsequent debriefing revealed that the anomalous period, unknown to the investigator, corresponded to an episode of severe marital disturbance in the life of the subject.

Others have attempted more elaborate examinations of the effects of emotion. In a correlational effort, Miller (1978b) compared RPA and standardized mood measurements across a period of several weeks. A relationship was observed which was most pronounced for those individuals with overall higher variability in RPA. Individuals with greater variability in day to day RPA demonstrated higher correlations between RPA and mood measures. In a similar study Miller and LeBeau (1982) attempted manipulation of stress by imposing a scoring procedure on the subject. They found that a shift toward greater accommodation, similar to that reported by Leibowitz (1976), but limited to individuals who scored high in anxiety. These reports suggest a correspondence between emotion and visual accommodation which is not yet clearly defined. They also suggest the influence of a more general involvement of the autonomic nervous system and the disruptive effects of introducing stress.

In summary, evidence supporting the existence and the stability of RPA describes a phenomenon which is common to ordinary human visual performance. It is well documented that, in the absence of adequate visual stimulation, accommodation regresses toward an individually specific intermediate resting focus. It is also well established that RPA varies greatly among individuals (Owens, 1987). This occurs in a variety of situations, including both darkened and well lit visual environments, and the tendency may be regarded as reasonably stable across time. Furthermore, it seems clear that individually specific RPA is subject to a number of predictable factors which contribute significant situational variance, among them are age, visual fatigue and stress.

FACTORS WHICH EFFECT REGRESSION TO RPA

Evidence concerning environments which provide less than adequate accommodative stimuli is of central importance to the present effort. It should be remembered that accommodation is controlled by both voluntary and autonomic influences (Marg, 1951; Randle, 1970). The focus of the present study is limited to visual performance involving autonomic control. This follows the earlier noted assumption that both sympathetic and parasympathetic

systems function to provide dual innervation to the ciliary muscle (Gawron, 1979) and that the characteristic drift toward RPA is explainable as a manifestation of the balance achieved between these opponent systems in the absence of adequate visual stimuli (Miller et al., 1983). The present effort is concerned with environmental and situational factors that affect the shift to RPA.

Accommodation generally declines with reduced quality and availability of stimulus input. Similarly, accommodative drift toward a resting posture is inversely related to the quality of the stimulus (Owens, 1987). Diminishing illumination offers perhaps the most intuitive example of such a performance degradation effect.

In an early effort Leibowitz and Owens (1975a) measured 30 emmetropic undergraduates as they viewed an exterior scene through a laboratory window. Accommodation was measured in four conditions, including full daylight, filtered daylight reduced by a factor of 0.0112 (i.e., approximating dusk), filtered daylight reduced by a factor of 0.000063 (i.e., approximating bright moon light) and total darkness. They found that subjects over accommodated across all conditions with a progressively greater error associated with decreased illumination. Significant correlations were obtained between all luminance conditions and RPA. The greatest correlation obtained for the lowest luminance level ($r = .70$, $p. 0.001$). Thus, it was concluded that: "As stimulus effectiveness is degraded by decreasing the luminance, accommodation is influenced less by the stimulus distance and is biased progressively toward the dark focus of accommodation (p. 1125)."

Johnson (1976) measured the accommodative accuracy of four otherwise emmetropic subjects in another early laboratory investigation. Each subject viewed a high contrast target, presented at optical distances up to infinity, under four luminance conditions (i.e., space averaging luminances for grating targets of 65.43, 6.54, 0.65 and 0.065 candelas per square meter). Again as expected, performance declined progressively with reduced stimulus quality. Accommodative responses became essentially flat for the lowest lumination level. Moreover, the low luminance focus was approximately the individual's RPA.

More recent reports have supported these conclusions. Epstein, Ingelstem, Jansson and Tengroth (1981) found the same shift across luminance levels of 120, 0.15 and 0.001 candelas per square meter for a mixed group of 163 emmetropic and ametropic subjects. Maddock et al. (1981), further observed that hyperopes and emmetropes demonstrated greater myopic shifts compared to myopes. In other words, those considered to have the best visual acuity were found among those who demonstrated the greatest accommodation shift and performance degradation.

Other investigations have considered visual qualities of the physical stimulus. Owens and Leibowitz (1975) measured accommodation for single, white, fixation point presentations and found that subjects were unable to maintain focus for targets subtending 8.2 and 1.05 minutes of arc. Luria

(1980) examined the same effect across a range of stimuli subtending 1 to 50 minutes and found accommodative deficiencies limited the smaller targets which subtended less than eight minutes. The somewhat intuitive conclusion from these results was that the characteristic shift to RPA and the concern for empty field myopia may be restricted to relatively small targets (Owens, 1987).

Wolfe and Owens (1981) investigated another aspect of stimulus quality in an interesting series of experiments concerned with color differences within stimuli. They pointed out that stimulus detail could be discussed with respect to chromatic variations as well as differences in luminance intensities. Paired color combinations of equal brightness provided chromatic contrast edges which were presented at different distances and at different luminance contrasts. These isoluminant chromatic contours were found to be insufficient stimuli for accurate accommodation. Once more, luminance information was implicated as a necessary stimulus element.

At least three investigations have considered the importance of color for proper accommodative control. Fincham (1951) compared 55 subjects for their ability to accommodate white, red and blue targets at varying optical distances. Targets consisted of a luminous area with superimposed black dots subtending 1 and 3 minutes of arc. Red and blue targets were achieved by imposing filters between the subject and the otherwise similar white lit target. He found that about 60% of his subjects experienced difficulty accommodating for the monochromatic targets, although none had problems with the same white lit target.

The logic of Fincham's effort assumed the involvement of chromatic aberration as a cue for accommodation. Campbell and Westheimer (1959) reinforced this concern in another experiment which required the subject to focus on a "high-contrast test object", in white light filtered to provide green luminance. As with Fincham, they found that some subjects demonstrated reduced abilities in monochromatic light. Specifically, only one of a total of four subjects demonstrate deficiency when accommodating to rapid changes in target distance. They also noted that the deficient subject eventually produced correct responses following some experience.

Charman and Tucker (1977) followed these investigations with a series of observations which considered accommodation for white and monochromatic situations. In the first, six subjects were required to focus on letters presented with 10 candelas per square meter lumination. Letter limbs subtended either one or eight minutes of arc, and color was manipulated by a combination of gelatin and neutral-density filters. Five of a total of six subjects accommodated properly without practice for all conditions in both white and monochromatic light (allowing for relative chromatic aberration across colors). The sixth, and only naive subject, was initially nonresponsive with accommodation fixed at RPA. Her performance improved to equivalent accuracy following the instruction: "try to keep the letter as clear as possible".

Several observations were drawn from these findings and from results of subsequent elaborative manipulations of a separate one subject sample. They concluded that accommodation inadequacies apparent in monochromatic situations were correctable with appropriate training. Furthermore, the only accommodation differences associated with monochromatic light were regarded as a result of the differential accommodation at different wave lengths, specifically resulting from chromatic aberration. Or, for some subjects, accommodation functions were degraded with reduced acuity at the blue end of the spectrum (Charman & Tucker, 1977).

RESEARCH ORIENTATION

These findings provide considerable information for additional investigation of visual performance. It seems clear that accommodation tends toward individually specific RPA in conditions of inadequate visual stimulation. The general estimate of RPA is well established as an individual variable, intermediate distance between the maximum far point and minimum near point accommodation. Estimates of approximately 1.3 diopters (.76 meters) with a range of 4.0 to 0.0 diopters (.25 meters to infinity) are typical of young, emmetropic, undergraduate students (Owens, 1987). Numerous authors (Mershon & Amerson, 1980; Miller, 1978a; Owens & Higgins, 1983) have reported that RPA demonstrates both and long term stability. Others (Amerson, 1980, 1983; Bentivenga et al., 1981, Owens, 1986; Owens & Wolfe-Kelly, 1987; Simonelli, 1983) have identified influences which affect temporary and permanent changes in the characteristic. Still other investigations have defined stimulus factors which contribute to the involuntary shift toward the resting posture. Both light level and target size are among the influences which are inversely related to maintenance of appropriate focus. Color presents a third as yet not as well understood potential influence.

Fincham (1951) observed inaccurate accommodation in monochromatic environments for more than half of his relatively large sample. Campbell and Westheimer (1958) also observed monochromatic deficiencies for a portion of their sample of four subjects, but noted that they disappeared with experience. Finally, Charman and Tucker (1977) reported the same finding in one of their six subjects, but again noted that the deficiency was ameliorated with very nominal training. The conclusions of each of these efforts suggested the differential influence of chromatic involvement across various monochromatic light environments.

These reports clearly fall short of a complete explanation of the role of color in the visual accommodation process. Interestingly, apparently all three studies utilized well motivated, well trained subjects. The latter two used experimenters as subjects and concluded that accurate accommodation could be achieved with proactive involvement. It seems reasonable to assume that at least a portion of their visual behavior demonstrated the influence of voluntary control. Nonlaboratory situations are often less motivating and more aversive than those described. Accurate autonomic control might be more typical of such situations. Absence of both voluntary and autonomic control may occur in environments with inadequate visual stimulation.

Available reports specifically questioned whether the lens system can achieve accurate focus in monochromatic stimulus environments. Somewhat more practical questions might ask which conditions are most detrimental for maintenance of accurate accommodation, and conversely, which conditions are most conducive to regression toward RPA? We currently accept that low light levels and small target size facilitate this shift. The following experiments investigated the influences of differential quasi-monochromatic light upon involuntary regression toward the resting point of accommodation. The first explored potential differences in visual accommodation behavior in red, green

and white environments across multiple evaluations in diminishing light levels. The second attempted to refine the technique of the first by focusing attention upon one marginally stimulating light level.

EXPERIMENT ONE

This experiment examined visual performance across a series of marginally stimulating environmental conditions. Three independent variables were manipulated: ambient color, light level and time on task. The first, and principal variable of concern, involved color of the visual environment. White was considered as full spectrum visible light. Red and green chromatic conditions were defined by dividing the visible spectrum at approximately 600 nanometers. The second and third variables served to provide a range of stimulus quality to an otherwise controlled environment. Ambient light intensity was manipulated across four levels including at least one which provided marginally adequate stimulation for maintenance of accurate accommodation. Accommodation was evaluated three times across each trial to examine the potential demotivating influence of time on task.

METHOD

Subjects

Twelve young, adult individuals participated as subjects. Criteria for participation included: acceptable visual acuity in both eyes; acceptable color vision; ability to detect and respond to laser generated speckle patterns; and, willingness to participate in an arduous research task. Characteristics of participants from a previous experiment were examined and a group of acceptable candidates were identified. Additional volunteers were solicited to achieve a total of six females and six males willing and acceptable for this effort. Ten subjects were undergraduate students at the University of South Dakota and two were individuals from the local community. Eleven participants received $20.00 remuneration and the twelfth received extra class credit. All participants were less than thirty years old and apparently unremarkable with regard to perceptual deficiencies and abilities.

Apparatus

An experimental environment was constructed similar to that illustrated in figure 1. Subjects were seated such that a viewing tunnel restricted their visual environment to a right monocular view of a 35 X 45 centimeter portion of an illuminated screen. The screen was constructed from a single sheet of white museum board (i.e., Rag Mat "100", Number 1150), front illuminated from a Kodak Ektagraphic III BR slide projector in the low mode. An EXR rated bulb was used to approximate CIE Standard Illuminant B. Differential light conditions were achieved by imposing high quality Kodak Wratten filters between the projector and the screen. Apparent brightness was balanced across white, red and green color conditions by the combinations of color and neutral density filters depicted in table 1. Different light level conditions were obtained by imposing additional Kodak Wratten Number 96 neutral density attenuating filters in combination to achieve the transmittance values indicated in table 2. Unfiltered target luminance was approximately 143

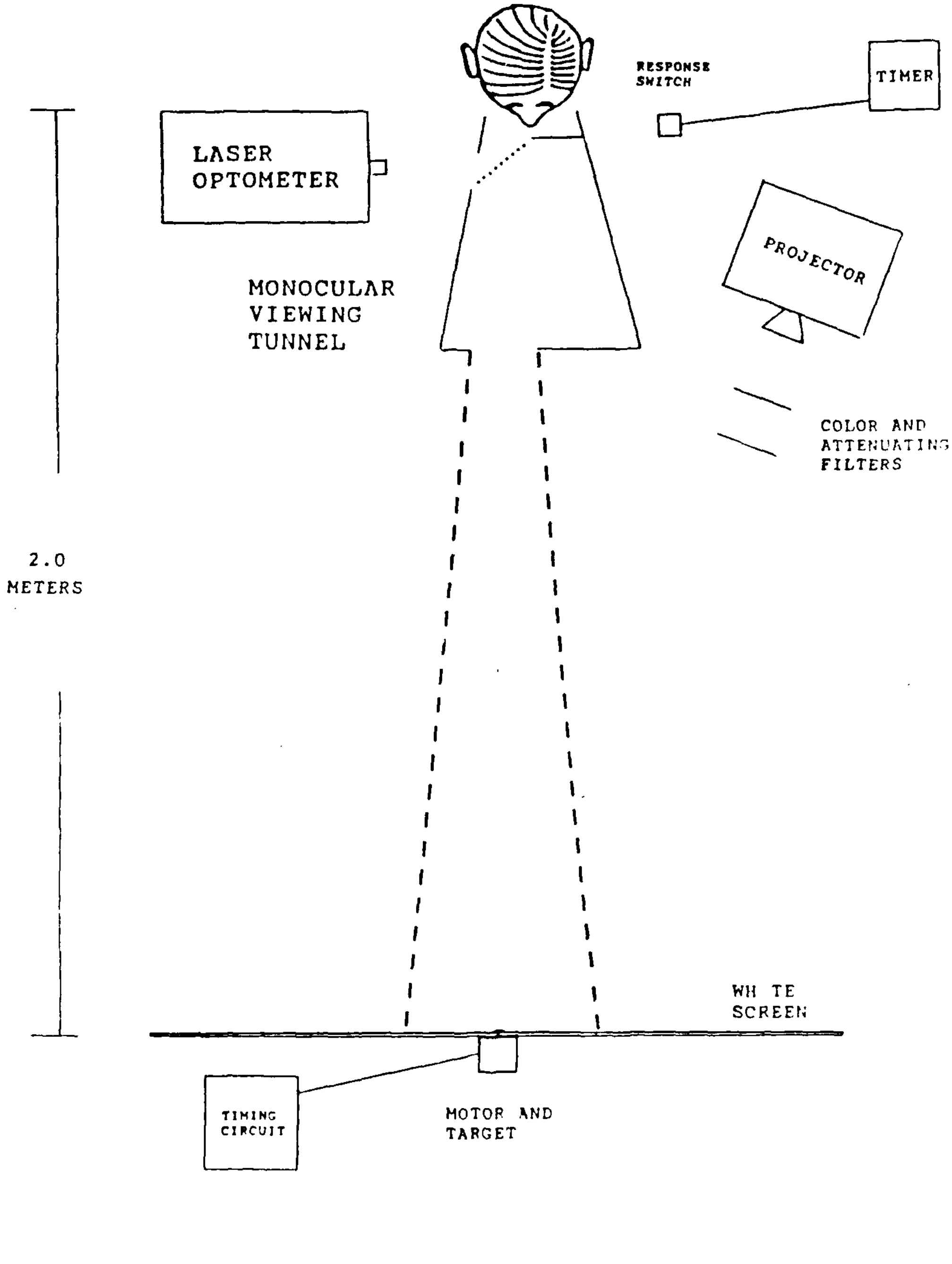


Figure 1. Schematic overview of the experimental environment.

Table 1

Specifications For Color And Attenuating Filters Required to Approximate Luminance Equivalence Across Color Conditions

	WRATTEN FILTER #	DOMINANT WAVELENGTH	% TRANSMITTANCE	LUMINANCE EFFICIENCIES *	COMBINED % TRANSMITTANCE **	ATTENUATING FILTER DENSITY	% ATTENUATING TRANSMITTANCE	% EFFECTIVE TRANSMITTANCE
WHITE	none	n/a	100%	100%	100%	0.7	19.95%	19.95%
RED	29	630	73.5%	26.5%	19.48%	none	100%	19.48%
GREEN	61	520	40.0%	71.0%	28.40%	0.1	79.40%	22.50%

* Following the Bouguer-Lambert law: total transmittance = % transmittance of the color Wratten filter X % transmittance of the attenuating filter. (Kodak, 1982)

** Following the CIE standard for luminosity factors (Kantowitz & Sorkin, 1983)

Table 2

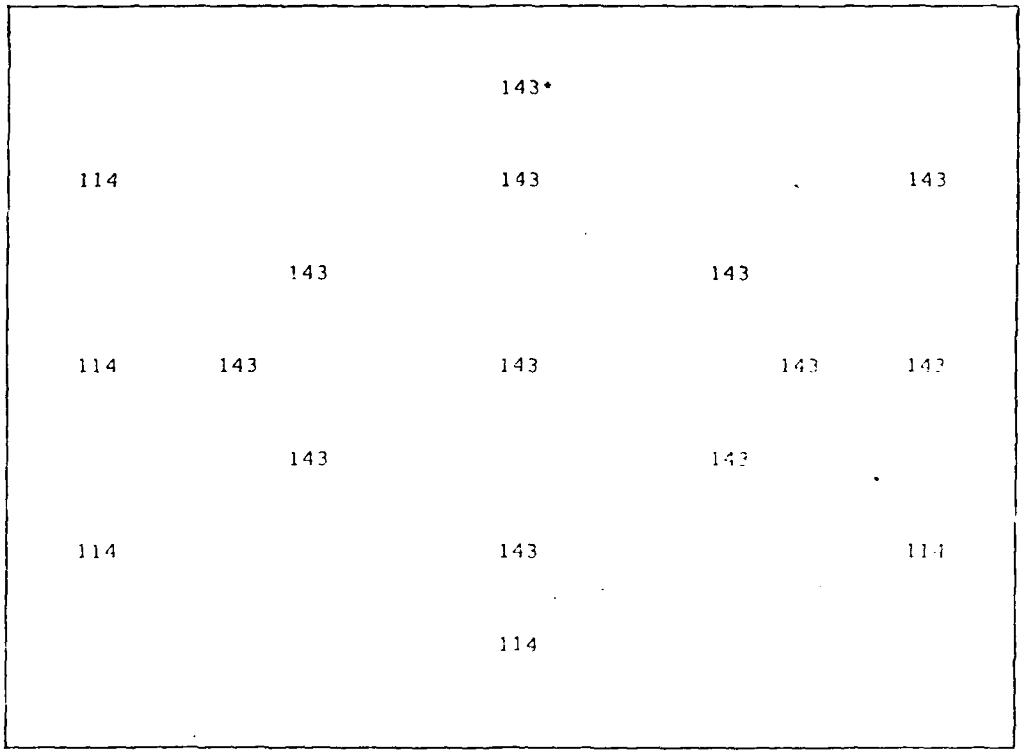
Specifications For Attenuating Filters Required To Achieve
Luminance Reduction Across Light Levels

	LIGHT LEVEL I (NO ADDITIONAL FILTERS)*	LIGHT LEVEL II (+ WRATTEN #96 N.D. 1.00)**	LIGHT LEVEL III (+ WRATTEN #96 N.D. 2.00)**	LIGHT LEVEL IV (+ WRATTEN #96 N.D. 1.00 AND N.D. 2.0)**
WHITE	19.95%	1.995%	.1995%	.01995%
RED	19.48%	1.948%	.1948%	.01948%
GREEN	22.50%	2.250%	.2250%	.02250%

* Percent effective transmittance, from table 1.

** Following the Bouguer-Lambert law: total transmittance equals the product of percent transmittance of the color Wratten filter and percent transmittance of the attenuating filter. (Kodak, 1982)

candelas per square meter (See figure 2). This suggests luminance values of approximately 28.5. 2.85, .285 and .0285 candelas per square meter for white light levels I, II, III and IV, respectively (following tables 1 and 2).



* Candelas per square meter

Figure 2. Approximate unfiltered luminance of the experimental visual environment.

A single, black Landolt C was positioned on a disc of the same size and presented at a distance of two meters in the approximate center of the observer's field of view. The overall diameter of the target C was 12.5 millimeters with a stroke width of 1.5 millimeters and a gap width of four millimeters. The disc was mechanically rotated at one revolution per minute by a high torque, twelve volt direct current motor. The rotating disc and the background were constructed of equivalent material and illuminated by the same light source.

Visual accommodation was measured with a laser-Badal optometer functionally identical to the principles set forth by Hennessy and Liebowitz (1970, 1972). Flashes of a laser light pattern were reflected from the surface of a rotating drum Briefly presented, the pattern remained consistently bright and focused, yet inadequate to stimulate the subject's accommodation. When viewed thru an improperly accommodated eye, the granular texture of the presentation appeared to move or flow. Conversely, the absence of movement was characteristic of an eye correctly accommodated with a retinal image conjugate to the optical distance of the rotating drum. Thus, the condition of the human lens system could be inferred by a procedure which localized the "no motion" observations within a series of presentations.

The components of the laser optometer are illustrated in figure 3. The beam from a one milliwatt helium-neon laser was diverged by a 50 diopter positive lens to provide the speckle pattern which was reflected from the slowly rotated drum. The position of the drum was variable relative to a five diopter positive lens. The subject's head was fixed relative to the lens by the forehead and chin rest of a viewing tunnel. A beam splitter was positioned between the observer's eye and the lens to facilitate viewing a pattern superimposed on the task environment. The arrangement of the positive lens and eye (i.e., separate by a fixed distance of one focal length) and the lens and the drum (i.e., separated at variable distances) is referred to as the Badal principle (Simonelli, 1980). This relationship can be fully described with the thin lens equation. Figure 4 provides the logic necessary for deriving the working equation used to determine the diopter value of the eye for any position of the drum relative to the lens. A standard correction appropriate to the 632.8 nanometer helium-neon laser was included to compensate for inherent chromatic aberration. A correction to determine the true plane of stationarity (i.e., the drum reference point from which to measure the variable drum to lens distance) was included following Charman (1974).

<u>Visual Performance Task</u>

Subjects were required to monitor the rotating Landolt C and to report infrequent periods during which rotation stopped. Stationary target periods were brief (i.e., 1.5 seconds or less), and intended to provide a difficult to detect, marginally effective target stimulus. Performance task stimuli were presented between the first and second halves of experimental trials. Stimuli

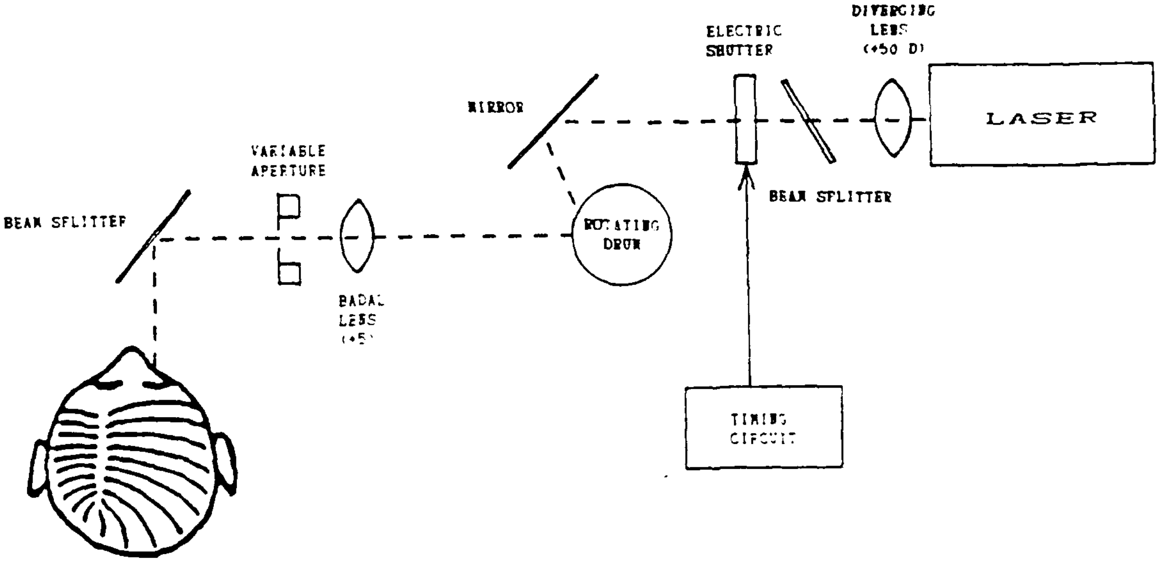
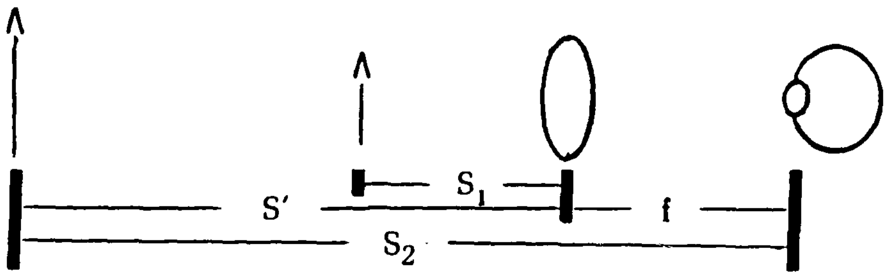


Figure 3. Schematic overview of the laser-Badal optometer.



Following the Thin Lens Equation: (when $S_1 < f$ S'_1 is negative) $\frac{1}{S_1} + \frac{1}{S'_1} = \frac{1}{f}$

$\frac{1}{S_1} - \frac{1}{S_2 - f} = \frac{1}{f}$ And $S' = S_2 - f$

$1 - \frac{S_1}{S_2 - f} = \frac{S_1}{f}$ When multiplied by S_1

$S_2 - f - S_1 = \frac{S_1 S_2}{f} - S_1$ When multiplied by $S_2 - f$

$S_2 \left(1 - \frac{S_1}{f} \right) = f$ By cancelling S_1 and rearranging

$\left(1 - \frac{S_1}{f} \right) = \frac{f}{S_2}$ When multiplied by $\frac{1}{S_2}$

$\frac{1}{f} - \frac{S_1}{f^2} = \frac{1}{S_2}$ When multiplied by $\frac{1}{f}$

For diopter values where $F = \frac{1}{f}$; $Q = \frac{1}{S_2}$; and $U = S_1$

$F - S_1 F^2 = Q$ Substituting

Correcting for chormatic aberration

$F_{corrected} = F - .33$

Correcting for the true plane of stationarity (following Charman, 1974)

$U_{corrected} = S_1 - 1.2$ (S_1 measured from the lens to the center of the drum)

** *WORKING EQUATION:* $F_{corrected} - U_{corrected} * F^2 = Q$ **

Figure 4. Justification of the working formula for determining accommodation using the laser-Badal optometer.

were not presented during evaluations or during dark adaptation. Forty percent of the three minute, half trial periods received no stimuli. No more than one target stimulus was presented during any single half trial period.

Subjects were expected to remain vigilant and report detection of target stimuli by quickly pressing a thumb switch. The vigilance requirement, however, was provided to facilitate involvement in the true visual performance task which was maintenance of accurate accommodation. Detection of target stimuli was not in itself a matter of experimental concern for this investigation.

Visual Performance Evaluation

Estimates of visual accommodation were inferred from subjective reports of apparent motion in the texture of speckle pattern presentations. A series of presentations were provided in each evaluation. Subjects verbally reported one of three possible observations for each presentation: 1) motion in the same direction as the rotation of the drum, when the individual's actual accommodation was for some point more distant than the virtual image of the test speckle pattern; 2) motion in the opposite direction, when the individual's actual accommodation was for some point less distant than the test speckle pattern; 3) or, motion which was poorly defined as "swirling" or "boiling", when the optical distance of the drum corresponded to the individual's condition of accommodation.

Method of limits and stair case procedures were used to bracket the subjects true accommodative state. Speckle patterns were presented at increasingly precise increments as the drum was moved toward the plane of stationarity until the subject reported a transition from "motion to no motion" followed by a transition from "no motion to motion in the opposite direction". The same procedure was completed moving the drum in the opposite direction. A stair case bracketing procedure was used to more precisely specify the location of perceived motion changes. The median point between opposite direction reports was regarded as the plane of stationarity. The accommodative state of the eye was calculated using the equation provided in figure 4.

Procedure

All subjects were examined for acceptable uncorrected visual acuity, color vision and ability to respond to laser light presentations. Acceptable vision was defined as a minimum of 20/20 near and far acuity, measured by performance on the Bausch and Lomb Master Ortho-rater. Acceptable color vision was established by Ishihara color plates (Ishihara, 1975). Proficiency with laser generated patterns used during optometric evaluations was determined following practice with the actual device.

All participants were briefed regarding the schedule, the task requirements and the monetary reimbursement or class credit provided for participation. Volunteers were provided an opportunity to read and sign an

informed consent statement prior to a participation. Questions regarding the experiment were answered without reservation and all subjects understood that they would not be deceived or covertly manipulated in any way.

Participants completed three sessions which occurred within sixty minutes of the same hour across a period of three days. Each session began with a ten minute dark adaptation period, during which the individual's RPA was evaluated in near total darkness. Experimental trials began with instructions to begin viewing thru the viewing tunnel, to watch the target and to quickly press the button when the target stops rotating. Each session was conducted in a single color condition and each session included four light level conditions. Light level manipulations were presented in consecutive six minute trials of decreasing light intensity punctuated by five minute dark adaptation periods. Visual performance evaluations were conducted initially, and after three and six minutes, to achieve three levels of time on task across each trial. The visual performance task was presented at approximately the first, second or third minute of each half trial (i.e., as determined from a random numbers table) but not more frequently than twice per trial.

RESULTS

Each participant received all treatments as repeated measures in this three color by four light level by three time on task design. A complete listing of acquired diopter values is provided in Appendix A. Appendix B provides the same information in graphic form. These data are summarized in table 3 and figure 5.

Results of an analysis of variance calculated for the total data set are presented in table 4. Notable features among these findings include main effects for color, light level and time on task independent variables. No significant interactions were revealed.

Results of initial visual performance evaluations for each color condition were regarded as the best estimate of the individuals correct accommodation, and therefore, served as a reference for comparison. Pearson Product Moment correlations were calculated for diopter values achieved in the first evaluation during each daily session and diopter values achieved in subsequent evaluations for each color condition. Table 5 and figure 6 provide complete results of these analyses.

Mean RPA values were estimated from available dark focus RPA evaluations. Acceptability of individual RPA measurements was based on judgements regarding the appropriateness with respect to consistency with other measurements and the apparent influence of specific focus tendencies resulting from experience in the experimental environment. Appendix C provides a listing of all available individual measures as well as a summary of the selection logic employed to achieve the final estimates. Pearson Product Moment correlations were calculated to estimate the relationship between individual RPA and measured accommodation values. Table 6 and figure 7 provide complete results of these analyses.

Table 3

Numeric Summary of Mean Diopter Values Calculated for
Red, Green and White Conditions in Experiment One

Light Level	Time On Task	Red $\bar{X}$	Red SD	Green $\bar{X}$	Green SD	White $\bar{X}$	White SD	Overall $\bar{X}$	Overall SD
I	1.	0.49	0.27	0.24	0.26	0.40	0.22		
	2.	0.45	0.21	0.23	0.26	0.37	0.20	0.38	0.25
	3.	0.54	0.26	0.20	0.30	0.48	0.32		
II	1.	0.38	0.22	0.16	0.36	0.33	0.28		
	2.	0.46	0.20	0.20	0.33	0.32	0.23	0.32	0.27
	3.	0.42	0.22	0.22	0.33	0.40	0.22		
III	1.	0.43	0.28	0.25	0.29	0.33	0.25		
	2.	0.57	0.23	0.26	0.39	0.36	0.24	0.39	0.29
	3.	0.54	0.26	0.33	0.38	0.41	0.28		
IV	1.	0.57	0.23	0.43	0.41	0.38	0.37		
	2.	0.63	0.26	0.46	0.58	0.42	0.58	0.50	0.41
	3.	0.69	0.24	0.43	0.53	0.47	0.52		
Overall (Color)		0.51	0.24	0.28	0.37	0.39	0.31		

Measurement	1.		2.		3.	
Overall (Time On Task)	0.37	0.29	0.40	0.31	0.43	0.31

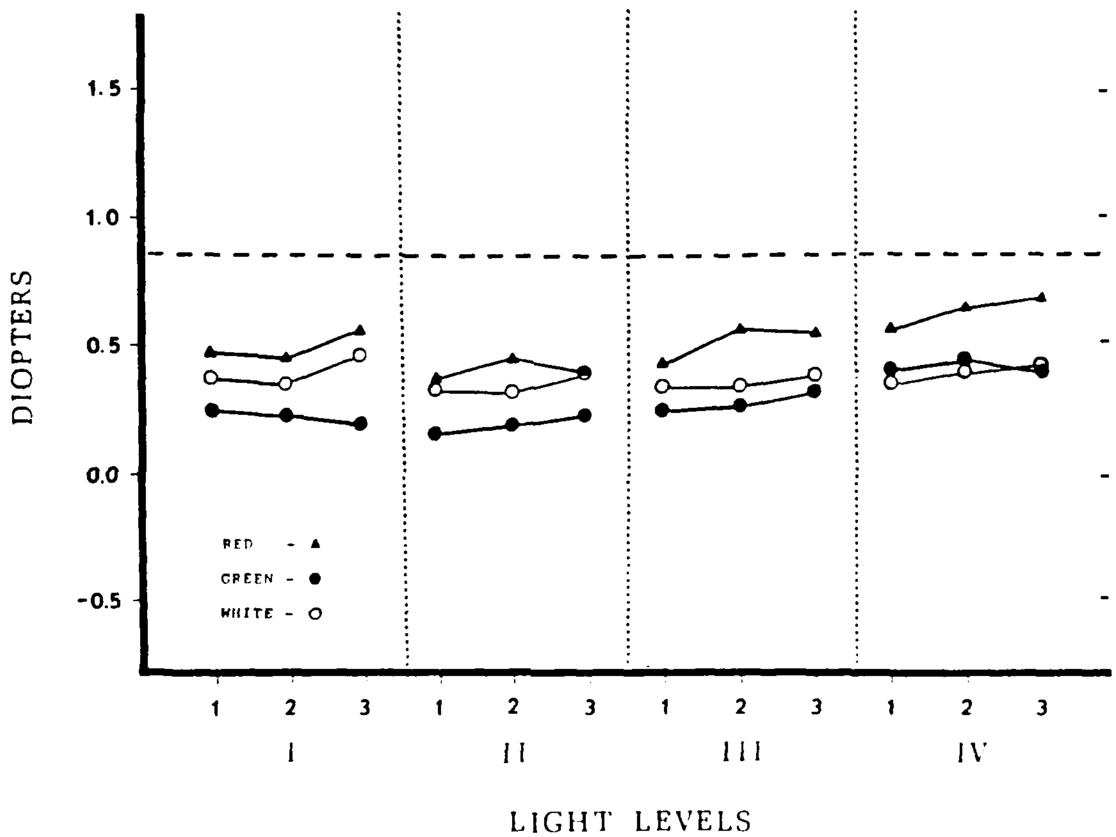


Figure 5. Graphic representation of mean diopter values achieved for red, green and white conditions in experiment one.

Table 4

Results of Analysis of Variance of Data Achieved From Color, Light Level and Time on Task Manipulations of Experiment One

Source	SS	dF	MS	F	PR F
Color	3.162	2	1.581	8.02	.003
	3.549	18	0.197		
Light Level	1.458	3	0.486	4.90	.008
	2.677	27	0.099		
Time on Task	0.226	2	0.113	6.68	.007
	0.304	18	0.017		
Color *	0.412	6	0.069	.76	.601
Light Level	4.848	54	0.090		
Color *	0.085	4	0.021	1.39	.256
Time on Task	0.547	36	0.015		
Light Level *	0.074	6	0.012	0.59	.740
Time on Task	1.132	54	0.021		
Color * Light Level	0.126	12	0.010	0.77	.681
* Time on Task	1.471	108	0.014		

Table 5

Numeric Summary of Correlation Values Calculated for Relationships between First and Subsequent Measurements of Accommodation for Red, Green and White Conditions in Experiment One

Light	Time On Task	Red r	Green r	White r
I	1.	1.0	1.0	1.0
	2.	0.82	0.90	0.90
	3.	0.77	0.94	0.82
II	1.	0.56	0.92	0.55
	2.	0.46	0.89	0.59
	3.	0.70	0.80	0.75
III	1.	0.74	0.76	0.62
	2.	0.74	0.73	0.52
	3.	0.53	0.77	0.80
IV	1.	0.13	0.61	0.56
	2.	0.61	0.66	0.70
	3.	0.41	0.64	0.76

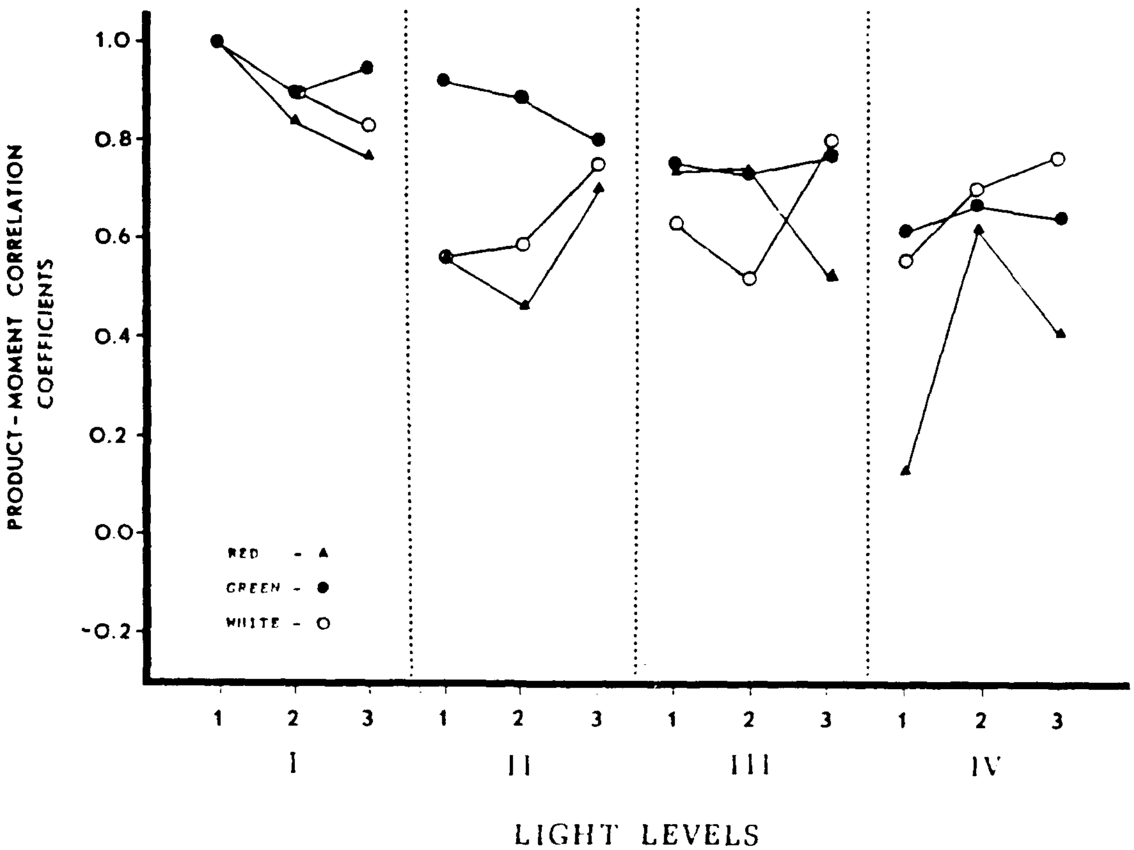


Figure 6. Graphic representation of correlation values calculated for relationships between first and subsequent measurements of accommodation for red, green and white conditions in experiment one.

Table 6

Numeric Summary of Correlation Values Calculated for Relationships Between RPA and Measured Accommodation for Red, Green and White Conditions in Experiment One

Light	Time On Task	Red r	Green r	White r
I	1.	.60	.48	.58
	2.	.49	.66	.52
	3.	.19	.61	.54
II	1.	.50	.70	.40
	2.	.59	.68	.31
	3.	.38	.77	.68
III	1.	.72	.59	.80
	2.	.66	.34	.89
	3.	.37	.45	.84
IV	1.	.24	.67	.32
	2.	.14	.59	.49
	3.	.07	.44	.43

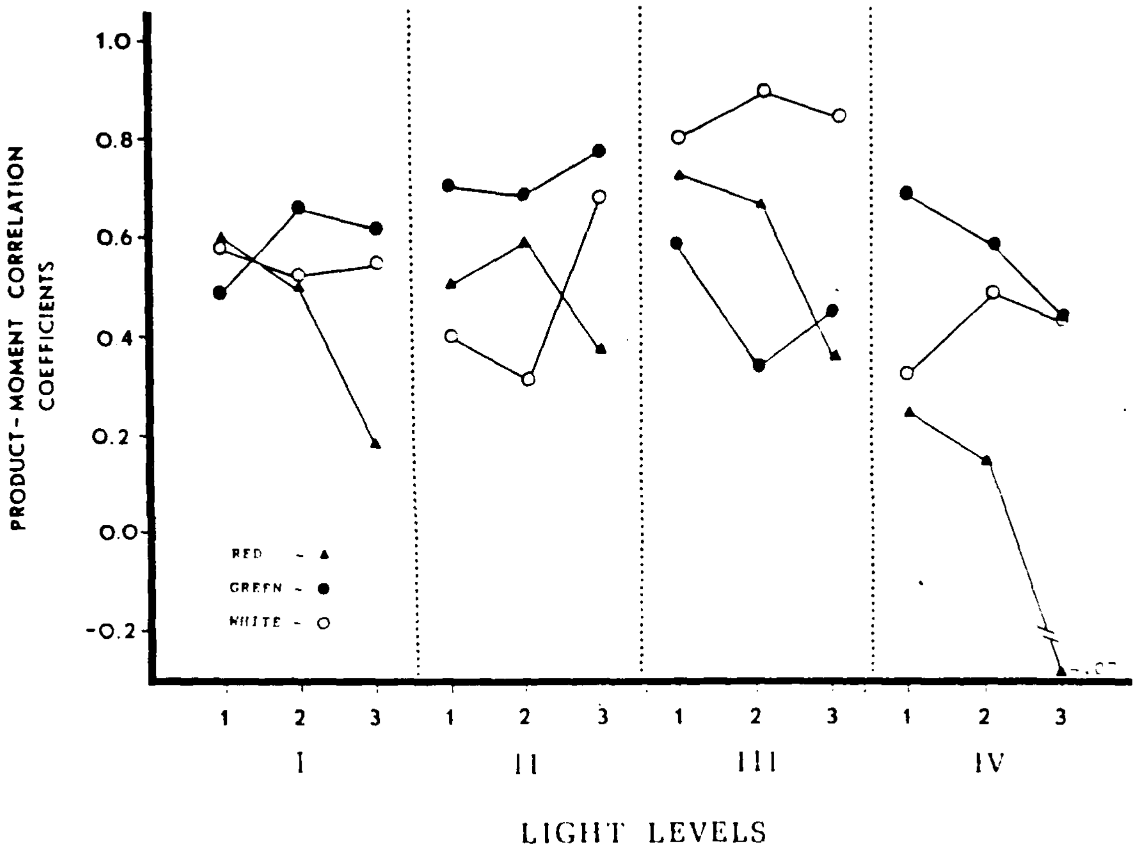


Figure 7. Graphic representation of correlation values calculated for relationships between RPA and measured accommodation for red, green and white conditions of experiment one.

Results from the visual performance task were not regarded as an appropriate measure of accommodation and therefore not considered as a concern for analysis. Complete response time data for this task are available in Appendix D. Subjective review of these data suggest that response times diminish with practice.

EXPERIMENT TWO

This experiment followed the results of the first and examined visual performance across different color environments presented at the same light level. Three independent variables were manipulated: ambient color, time on task and replication of equivalent trial presentations. As with the first experiment, ambient color was the chief variable of concern. Time on task and replication were included to provide a range of stimulus quality. Light intensity manipulation was limited to a single marginally stimulating level, following the findings of experiment one.

METHOD

Subjects

Two male and four female subjects were selected from experiment one to participate in the second investigation. Criteria for participation were: location of RPA relative to the target distance; ability to respond during visual performance evaluations; and, willingness to continue participation in the research project. Five subjects received $10.00 remuneration for a single session. The sixth participated for extra class credit.

Apparatus

Equipment and equipment arrangement were equivalent to those used in experiment one. Color filter combinations described in table 1 were used to achieve red, green and white environmental color conditions. A single light level of approximately .285 candelas per square meter was achieved by including a Kodak Wratten Number 96, 2.0 neutral density filter.

Procedure

Each participant was seated in the experimental cubicle and permitted to dark adapt for ten minutes prior to observing the target stimulus. Each trial was initiated by instructing the individual to begin viewing thru the viewing tunnel, to watch the target and to quickly press the button when the target stopped rotating. As with experiment one, each session consisted of a series of six minute trials and five minute rest periods. A total of six trials were conducted and visual performance evaluations were attempted at three intervals during each trial: initially, after three minutes and after six minutes. Visual performance task stimuli were presented following the same randomization method as experiment one. All color conditions were presented twice during a single experimental session and light level was not varied. Order of color presentation was staggered to minimize the potential affects of fatigue.

RESULTS

Each participant received all treatments as repeated measures in this three color by three time on task by two replication design. A complete listing of acquired diopter values is provided in appendix E. Appendix F provides the same information in graphic form. These data are also summarized in table 7 and figure 8.

Results of an analysis of variance calculated for the total data set are presented in table 8. No significant main effects were evident from this analysis, however, a significant interaction between color and replication was revealed.

As with experiment one, results of initial visual performance evaluations for each color condition were regarded as the best estimate of correct accommodation. Pearson product moment correlations were calculated for diopter values achieved in the first and subsequent evaluations of each color condition. Table 9 and figure 9 provide complete results of these analyses.

Pearson product moment correlations were also calculated to estimate the relationships between individual RPA (i.e., following Appendix C) and measured accommodation values. Table 10 and figure 10 provide complete results of these analyses.

Appendix G provides complete response time data for the visual performance task which was again not considered as a measure accommodation.

Table 7

Numeric Summary of Mean Diopter Values Calculated for Red, Green and White Conditions in Experiment Two

Replication	Time On Task	Red $\bar{X}$	Red SD	Green $\bar{X}$	Green SD	White $\bar{X}$	White SD	Overall $\bar{X}$	Overall SD
I	1.	0.38	0.27	0.40	0.47	0.32	0.24		
	2.	0.42	0.46	0.34	0.30	0.32	0.34	0.38	0.36
	3.	0.51	0.40	0.33	0.38	0.41	0.35		
II	1.	0.39	0.38	0.44	0.48	0.36	0.35		
	2.	0.28	0.36	0.45	0.49	0.43	0.38	0.39	0.40
	3.	0.28	0.17	0.49	0.54	0.37	0.47		
Overall (Color)		0.38	0.34	0.41	0.44	0.37	0.36		

Measurement	1.		2.		3.	
Overall (Time On Task)	0.38	0.37	0.37	0.39	0.40	0.39

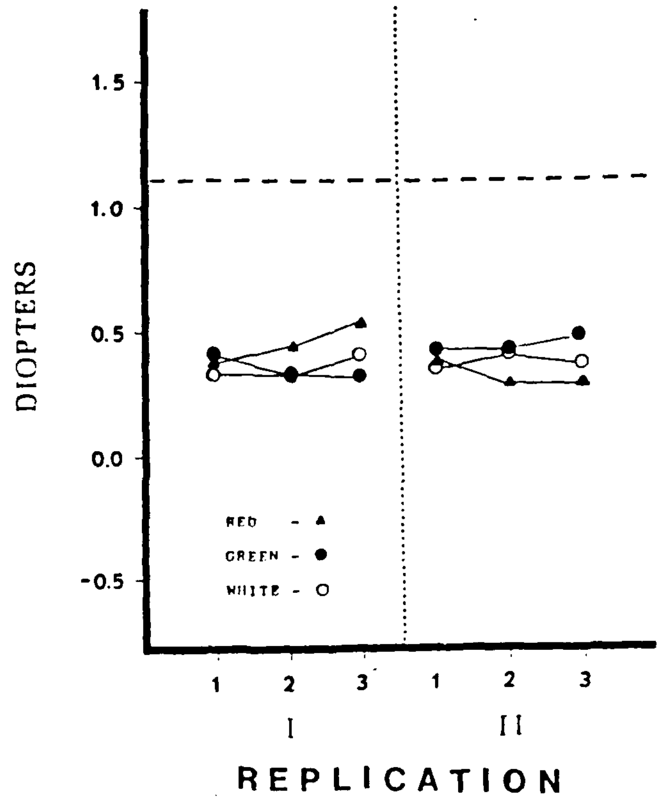


Figure 8. Graphic representation of mean diopter values calculated for red, green and white conditions of experiment two.

Table 8

Results of Analysis of Variance of Data Achieved from Color, Time on Task and Repetition Manipulations of Experiment Two

Source	SS	df	MS	F	PR F
Replication	0.001	1	0.001	0.02	.889
	0.248	5	0.050		
Color	0.032	2	0.016	0.41	.673
	0.385	10	0.038		
Time on Task	0.013	2	0.006	0.59	.571
	0.106	10	0.011		
Replication	0.246	2	0.123	4.23	.047
* Color	0.291	10	0.029		
Replication	0.024	2	0.012	0.78	.484
* Time on Task	0.152	10	0.016		
Color *	0.025	4	0.006	0.30	.874
Time on Task	0.413	20	0.021		
Replication *	0.114	4	0.029	0.22	.333
Color * Time on Task	0.468	20	0.023		

Table 9

Numeric Summary of Correlation Values Calculated for Relationships between First and Subsequent Measurements of Accommodation for Red, Green and White Conditions in Experiment Two

Replication	Time On Task	Red r	Green r	White r
I	1.	1.0	1.0	1.0
	2.	0.93	0.87	0.98
	3.	0.95	0.83	0.98
II	1.	0.88	0.91	0.95
	2.	0.89	0.97	0.70
	3.	0.91	0.95	0.98

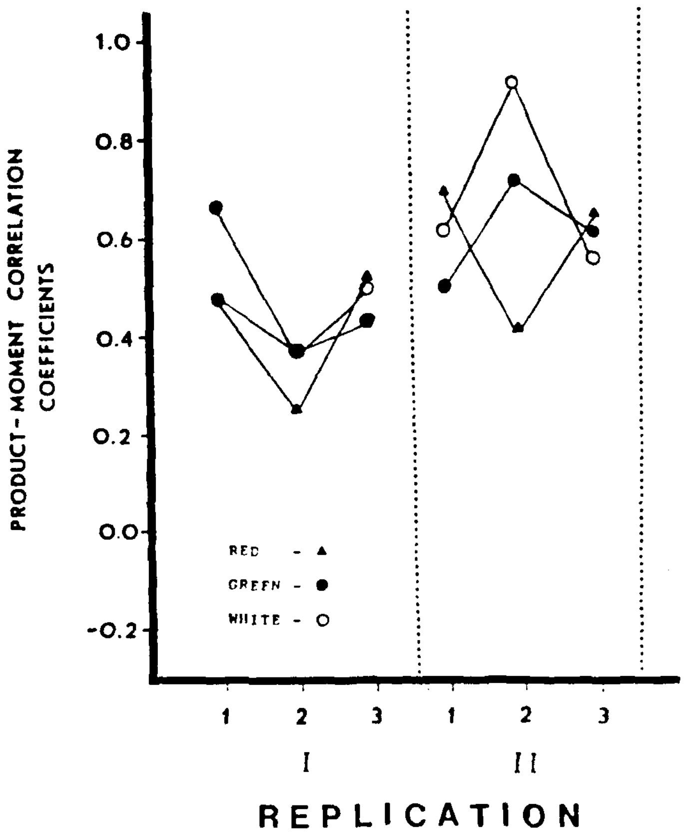


Figure 9. Graphic representation of correlational values calculated for relationships between first and subsequent measures of accomodation for red, green and white conditions of experiment two.

Table 10

Numeric Summary of Correlation Values Calculated for Relationships Between RPA and Measured Accommodation for Red, Green and White Conditions in Experiment Two

Replication	Time On Task	Red r	Green r	White r
I	1.	0.48	0.66	0.47
	2.	0.26	0.37	0.37
	3.	0.53	0.43	0.51
II	1.	0.70	0.50	0.61
	2.	0.41	0.72	0.92
	3.	0.65	0.62	0.56

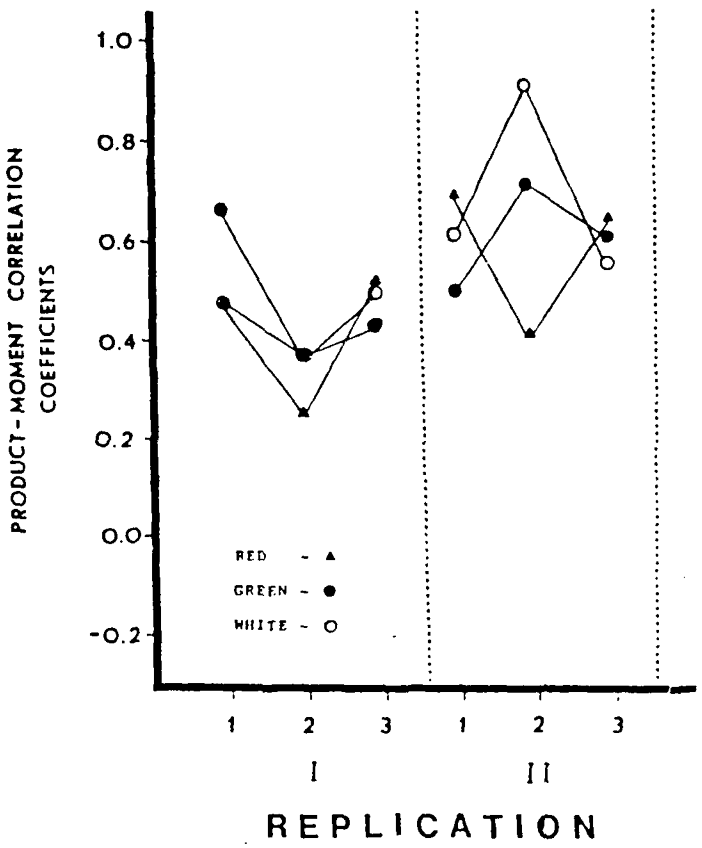


Figure 10. Graphic representation of correlational values calculated for relationships between RPA and measured accommodation for red, green and white conditions in experiment two.

DISCUSSION

The two investigations of the present effort were intended to explore the importance of ambient color as a factor associated with involuntary regression toward the resting point of accommodation. The first employed a broad based approach which provided data across several variables and served to identify a specific light level for additional investigation. The second investigation considered two separate replications of red, green and white color environments. The results of these efforts may be discussed with respect to the general findings of the total sample as well as the specific behavior of individual participants. The summarized statistics available in the results section provide focus for the general findings. Detailed results obtained from individual participants are available in Appendices A, B, E and F.

Three perspectives were employed to explore potential results of experimental manipulations and the possibility of relationships among subjects. The effects of manipulating the independent variables were considered in separate analyses of variance for each experiment. Trends associated with maintenance of correct accommodation, and conversely trends associated with regression toward RPA were considered in separate correlational analyses for each experiment.

FINDINGS OF THE ANALYSIS OF VARIANCE

Significant effects were revealed for all three independent variables in experiment one. Each significant main effect deserves attention, although none are experimentally interesting or central to the concerns of the present investigation. The general absence of significant interactions in these results provide a more direct summary comment regarding the potential of color related shifts and therefore also deserves discussion.

Significant differences among color conditions follow the order expected as a result of chromatic aberration in the observer's lens. It is commonly understood that the human eye is relatively hyperopic for red environments and myopic for green environments (Boff, Boff, K., Kaufman, L,; Thomas, J. 1986). Thus, greater and lesser accommodation is expected for red and green environments relative to the white condition. The presence of this main effect reflects accurate evaluation of an independent physiological phenomenon.

Significant differences among light level conditions were a planned and required element of the experimental design. Light levels were selected and pretested to ensure a range of stimulus quality. Earlier reports (Johnson, 1974; Epstein, et al., 1981) indicated that variation of intensity across similar white light luminance values resulted in a decline of accurate accommodation and a shift toward RPA. The absence of this main effect would have suggested a serious shortcoming in achieving the methodological objectives of the present effort. Conversely, the presence of a significant main effect serves to validate the experimental design.

Significant differences across time on task suggest successful achievement of a decline in motivation. Intra-trial differences in visual performance evaluations evidence a drift from correct accommodation which appears to provide an example of the commonly reported vigilance decrement. As with the main effect across light level, this result simply validates the intent of the experimental design. Time on task appears to be an effective variable for manipulating maintenance of accurate accommodation.

The presence of significant main effects are evidence of the effectiveness of the experimental manipulations and the efficacy of the experimental design. Visual performance declined as the available stimulation became increasingly inadequate and with extended time on task. The present investigation questioned whether such a decline occurred differentially for different color environments. The absence of significant interactions in the first experiment fails to support such a possibility.

Experiment two attempted a closer scrutiny of the behavior observed in the first effort. Although not a true replication, these observations were intended to be more focused but approximately comparable with the first effort. It was hoped that greater efficiency could be achieved by repeatedly evaluating behavior in the same marginally adequate light level. All evaluations were conducted during a single session, thereby eliminating the potential for intersession differences. Each color condition was repeated twice to provide more extended time on task and more visual performance measures. The sample population was refined to include only experienced participants with skill and practice in performing the experimental task. Results of this refined technique were surprisingly void of significant effects. No main effects and only one significant interaction were obtained. Variance among mean diopter values appeared to diminish with experience.

The most obvious conclusions following these analyses of variance suggest a reasonable level of efficacy in the experimental method for relatively naive individuals. Increased experience, however, greatly attenuated the effect. Perhaps more important, the lack of interactions among conditions strongly suggested the absence of a differential accommodation response across color conditions.

INTER-EVALUATION RELATIONSHIPS

A second, less formal analysis of the same data was attempted by correlating good estimates of individually specific correct accommodation with accommodation values obtained across the full range of each color condition. Logically, the magnitude of such correlations should have declined with corresponding decrements in the quality of the visual stimulus environment. The intent of this approach was to eliminate the influence of chromatic aberration and thereby provide a more understandable summary of visual performance evaluations.

Results from experiment one demonstrated the expected trend with declining magnitude in coefficient values across light levels. No such trend was apparent in the same analysis of experiment two which obtained larger coefficients and more consistent results. Overall, no striking differences between color conditions are apparent from subjective review of these correlational results. This finding is in agreement with the general absence of interactions revealed in the results of the analyses of variance.

RPA AND VISUAL PERFORMANCE

A third analysis was attempted which more directly addressed the central concern of this research effort: the possible association between ambient environmental color and regression to RPA. This correlational effort compared estimates of individually specific RPA with the accommodation values obtained across the full range of each color condition. As with the above method, it was hoped that results from this informal exploratory approach would provide more understandable information and direction for future investigation.

Results from experiment one demonstrated the expected trend toward stronger correlation coefficients as light decreased across levels one, two and three. Behavior in light level four failed to support this trend. Coefficients also increased between the first and second replications of experiment two. No identifiable order of the effect among color conditions and light levels or replications or experiments was apparent. Again, the overall analysis of these results is consistent with the previous findings. No color related differences were revealed.

DIFFERENCES AMONG SUBJECTS

Participants in these investigations were preselected for maximum similarity of visual abilities. Individual behavior in the experimental situation was somewhat less than entirely consistent. Two participants in the first study were excluded as a result of grossly inconsistent visual performance evaluations. The remaining ten varied considerably with respect to the averaged trends reported in the above descriptive statistics as well as with respect to precision demonstrated in visual performance evaluations. Review of the more complete results for experiment one presented in Appendices A and B indicate differences in baseline accommodation across individual subjects. Order and magnitude of effect are also somewhat inconsistent among individuals.

The results for subject three, depicted in figure 11, are perhaps the best example of intra-subject precision. These values are remarkable for both consistency in order of color effect as well as consistency across repeated evaluations. Not apparent are the capabilities observed during the actual evaluations. Subject three seemed relatively unchallenged by the laser light, speckle pattern detection task required during the visual performance evaluations. Her subjective reports of motion direction changes were unusually specific. And moreover, her precision remained constant across all light conditions.

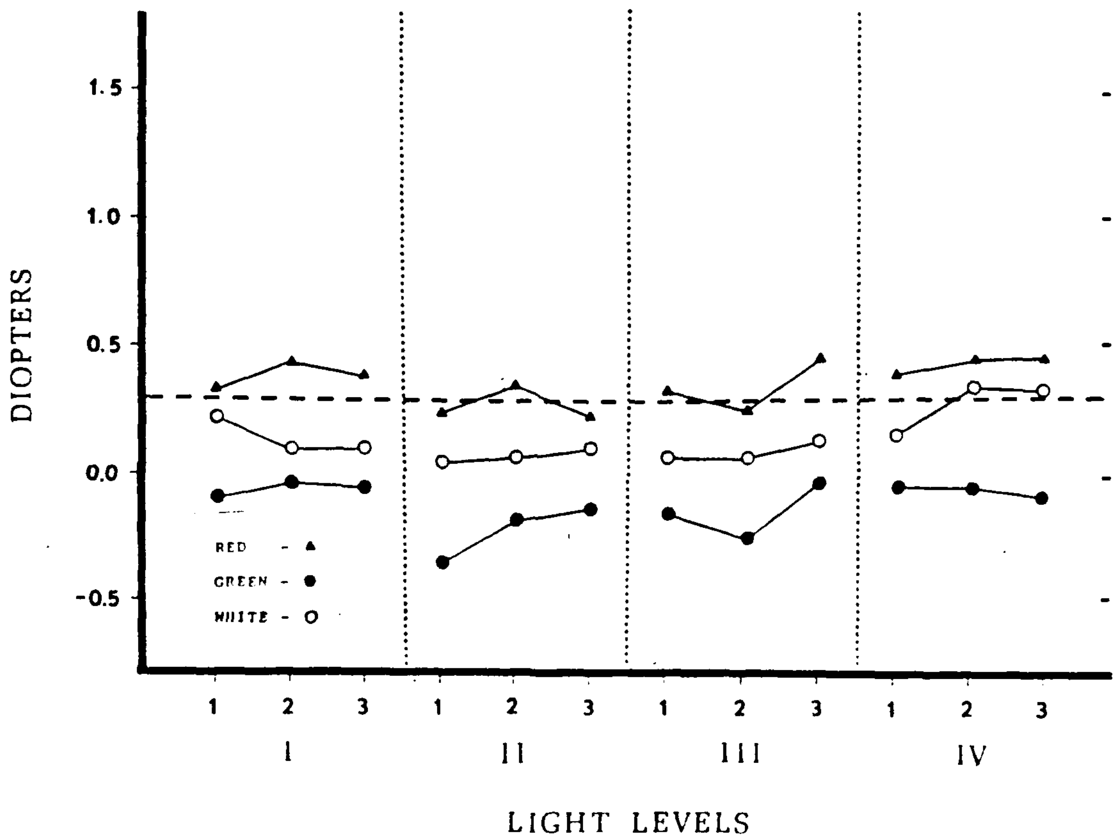


Figure 11. Graphic representation of diopter values achieved in red, green and white conditions for subject 3.

A somewhat different example is provided in the results for subject two depicted in figure 12. These reflect a similar exacting ability for accommodative style in the brighter conditions. Unlike subject three, however, his precision declined radically with reduced light in the third and fourth conditions. Also interesting was the apparent absence of differential accommodation typical of the other subjects for the three color conditions. This individual did not demonstrate the obvious influence of chromatic aberration so evident in the descriptive summaries of experiment one.

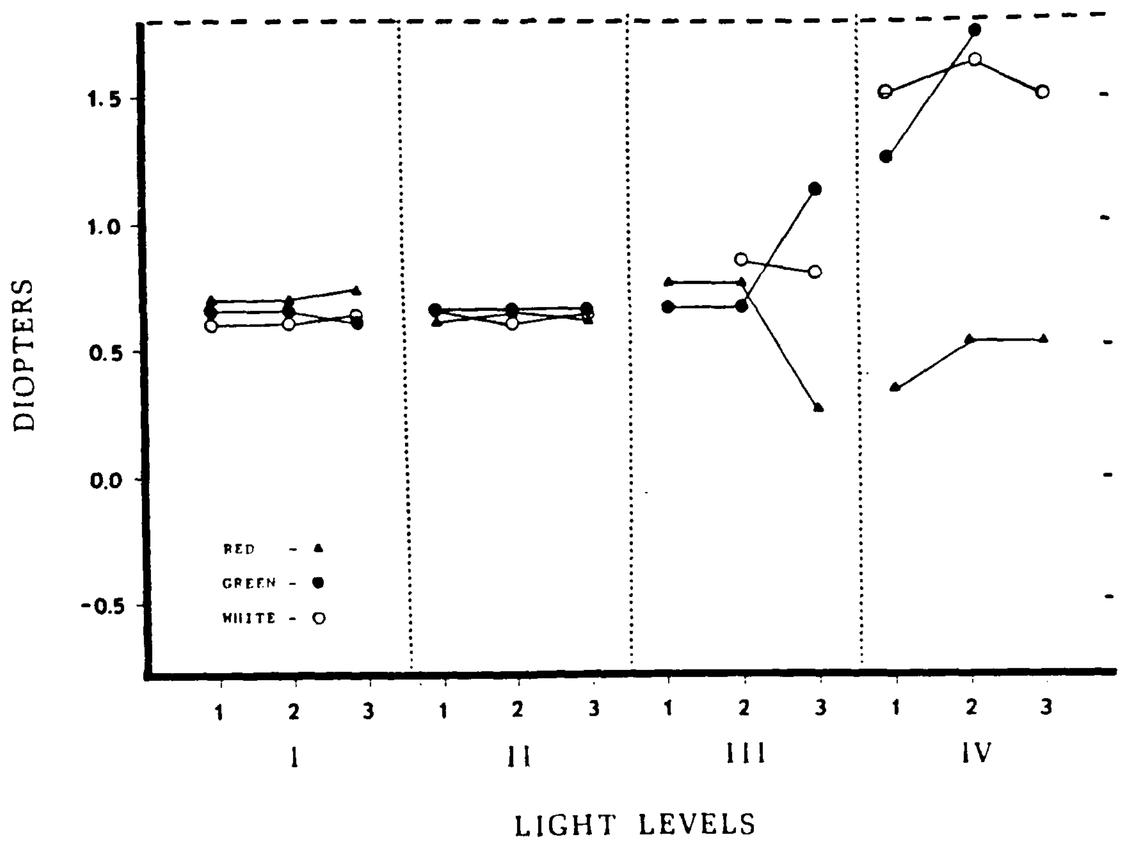


Figure 12. Graphic representation of diopter values achieved in red, green and white conditions for subject 2.

These specimen subjects demonstrated differential accommodation in spite of their impressive precision during the visual performance evaluations. A cursory review of other, less precise participants suggests the presence of at least one additional variable. The baseline accommodation suggested by the initial evaluations in each color condition varied markedly across individuals as well as across color conditions. Initial white measurement, for example, ranged from .02 to .97 diopters around a mean of .40 diopters (see appendix A).

A complete explanation of individual differences is beyond the scope of the present report. It should be noted that individual accommodation behavior in these experiments seemed to be influenced by multiple factors. Variations in retinal sensitivity, differential chromatic aberration and differences among autonomic control systems (i.e., as influenced by personal and situational conditions) may number among the topics for future theoretical attention.

MOTIVATION AND EXPERIMENTAL PERFORMANCE

Several aspects of these findings suggest that motivation may have influenced individual voluntary control of accommodation. Participants frequently expressed interest and concern for their performance. Mean response time for the visual performance task typically improved across daily sessions in the first experiment. And, three of the twelve subjects modified their responses during the later dark focus RPA evaluations to values approximately equal to the experimental viewing distance. Twenty five percent of the sample spontaneously shifted their accommodation response to approximate the experimental distance while in near total darkness and while not required to perform the visual performance task.

Surprisingly little statistical evidence emerged to support the presence of motivation. Results of the analyses of variance for experiment one indicated the appropriate main effect for time on task which was intended as an experimental manipulation to reduce motivation. Results of the correlational analyses are less clear on this point and fail to indicate an obvious trend when submitted to subjective review. Results of the Analysis of Variance of experiment two also fail to reveal a main effect across replications. The correlational analyses, however, suggested the possibility of a decrement in accommodation accuracy and a shift to RPA. One interpretation of the general lack of consistency and absence of main effects in the second experiment would point to the possibility of increased subject involvement and increased voluntary control of accommodation.

SUMMARY

The above effort was a broad exploratory examination of the significance of color for visual performance. Specifically, this effort considered the importance of red, green and white environments and potential differences associated with regression to RPA. Previous studies have directed attention to the importance of color in human visual accommodation but generally ignored influences inherent in the laboratory situation. Subject involvement, expectation and motivation may have provided for considerable voluntary control in visual performance during those efforts. This investigation attempted a more comprehensive approach which included a range of environmental light conditions, a range of color environments and repeated measures across an extended performance task. Time on task was introduced to provide for examination of a more complete range of motivation. Multiple light levels were included to better examine influences of color relative to shifts from correct accommodation, toward individually specific RPA.

Analyses of these results do not suggest previously unknown relationships between monochromatic visual environments and RPA. This conclusion does not support the earlier findings of Fincham (1951) who reported differences in accommodation for some subjects in a more restricted research environment. It does, however, support the opinions of others (Campbell & Westheimer, 1959; & Charman & Tucker, 1977) who also failed to find substantial differences among well trained subjects.

The present results were obtained across a range of visual stimulus conditions which included both marginally adequate as well as inadequate visual stimulus environments. The results do not suggest differential regression toward RPA, although the subjects were required to perform a very difficult task. This effort clearly falls short of the full range of topics relevant to determining optimal ambient illumination. Likewise, it does not satisfy the full range of more basic theoretical questions which can only be considered with much greater control of stimulus variables. It does, however, strongly suggest that decisions regarding optimal design for maintenance of correct accommodation may be made independent of color of the ambient light environment. This conclusion indicates that future applied research in this regard is not warranted.

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APPENDIX A

DIOPTER VALUES ACHIEVED FROM EVALUATIONS CONDUCTED IN EXPERIMENT ONE

SUBJECTS

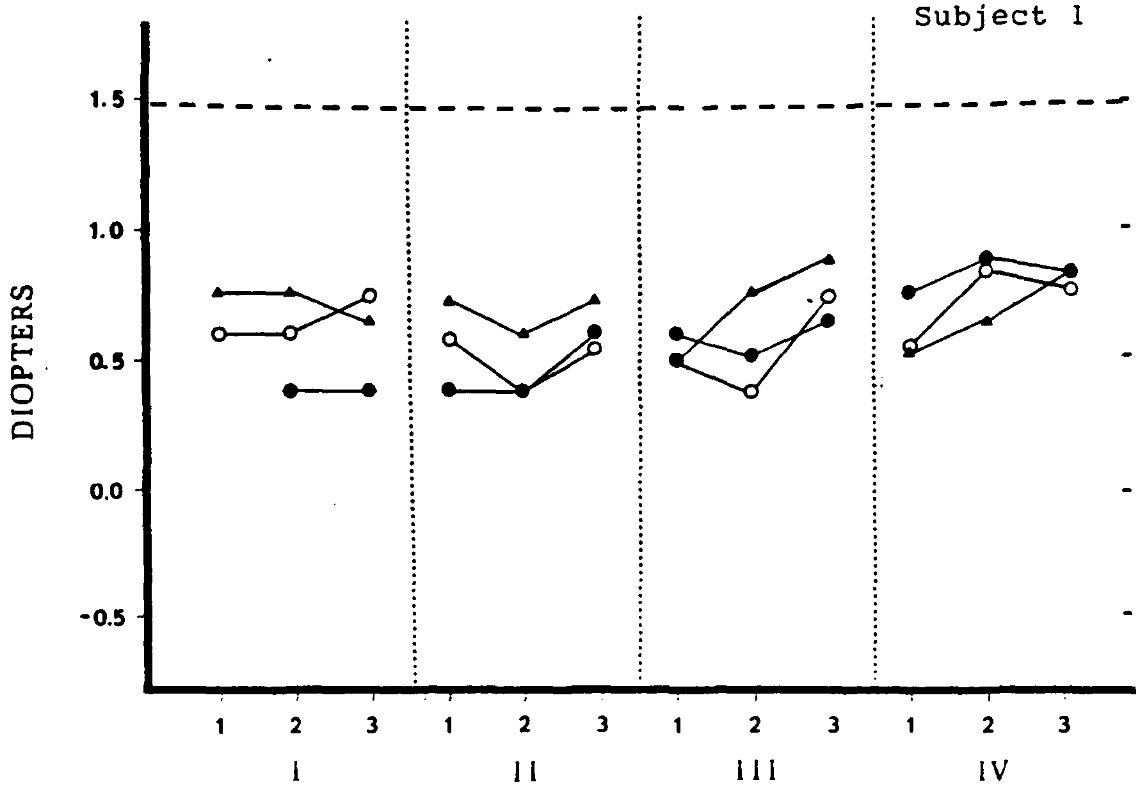
RED	1	2	3	4	5	6	7	8	9	10	11	12
	.77	.70	.35	N/U	.77	.52	.27	.90	.10	.52	.65	.15
Level 1	.77	.70	.45	N/U	.65	.32	.27	.52	.27	.40	.65	.15
	.65	.72	.40	N/U	1.02	.32	.52	.77	.10	.90	.77	.27
	.72	.60	.25	N/U	1.15	.32	.35	.27	.35	.27	.69**	.02
Level 2	.60	.65	.35	N/U	1.02	.52	.72	.40	.27	.27	.69**	.15
	.72	.60	.22	N/U	.80	.27	.47	.40	.02	.52	.69**	.27
	.50	.77	.32	N/U	.90	.65	.35	.52	.10	.22	.85	.02
Level 3	.77	.77	.27	N/U	.77	.65	.65	.65	.22	.42	.90	.35
	.90	.27	.47	.35	.90	.70	.65	.77	.10	.27	.77	.52
	.52	.35	.40	N/U	.62	.52	.60	.65	.15	.88*	.72	.90
Level 4	.65	.52	.47	N/U	.52	.65	.65	.90	.02	.90	.90	.65
	.85	.52	.47	N/U	.82	.52	.77	.85	.22	.85	.90	.90
GREEN												
	.40**	.65	-.08	M	N/U	.27	.27	-.11	.15	.27	.60	.02
Level 1	.40	.65	-.03	M	N/U	.40	.40	-.16	.02	.22	.35	.02
	.40	.60	-.06	M	N/U	.40	.27	-.23	.02	.27	.52	-.23
	.40	.65	-.36	N/U	N/U	.45	.17	-.11	.02	.22	.52	-.36
Level 2	.40	.65	-.18	N/U	N/U	.45	.17	-.03	.02	.35	.52	-.36
	.60	.65	-.13	N/U	N/U	.45	.10	.15	.15	.10	.52	-.36
	.60	.65	-.16	N/U	N/U	.17	.22	.35	.15	.27	.52	-.23
Level 3	.52	.65	-.23	N/U	N/U	.02	.15	.40	.10	.52	.85	-.36
	.65	1.10	.02	.35	N/U	-.01	.12	.35	.02	.35	.72	.02
	.77	1.22	-.03	N/U	N/U	.40	.17	.65	-.11	.65	.47	.10
Level 4	.90	1.72	-.03	N/U	N/U	.15	.47	.65	.02	.65	.47*	-.36
	.85	1.47*	-.08	N/U	N/U	-.11	.65	.60	.02	.65	.47*	-.23
WHITE												
	.60	.60	.22	.97	.77	.40*	.72	.52	.15	.40	.35	.02
Level 1	.60	.60	.10	N/U	.90	.27	.60	.52	.15	.35	.27	.22
	.75	.62	.10	1.72	.92	.52	.77	.65	.10	.35	.90	.02
	.57	.65	.05	.68	-.41	.27	.40	.02	.27	.40	.75	-.11
Level 2	.40	.60	.07	M	.65	.22	.40	.15	.30	.52	.60	-.11
	.55	.62	.10	N/U	N/U	.52	.40	.52	.27	.47	.60	-.03
	.50	.83**	.07	N/U	.77	.47	.27	.27	.02	.27	.52	.10
Level 3	.40	.85	.07	N/U	.60	.65	.22	.40	.22	.27	.40	.10
	.77	.80	.12	N/U	.77	.60	.40	.47	.27	.40	.40	-.11
	.55	1.12	.15	N/U	.65	.02	.60	.02	.10	.40	.72	.10
Level 4	.85	1.62	.37	N/U	.97	.02*	.47	.27	-.16	.60	.60*	-.48
	.77	1.50	.35	N/U	.52	.02*	.65	.52	-.03	.77	.52	-.36

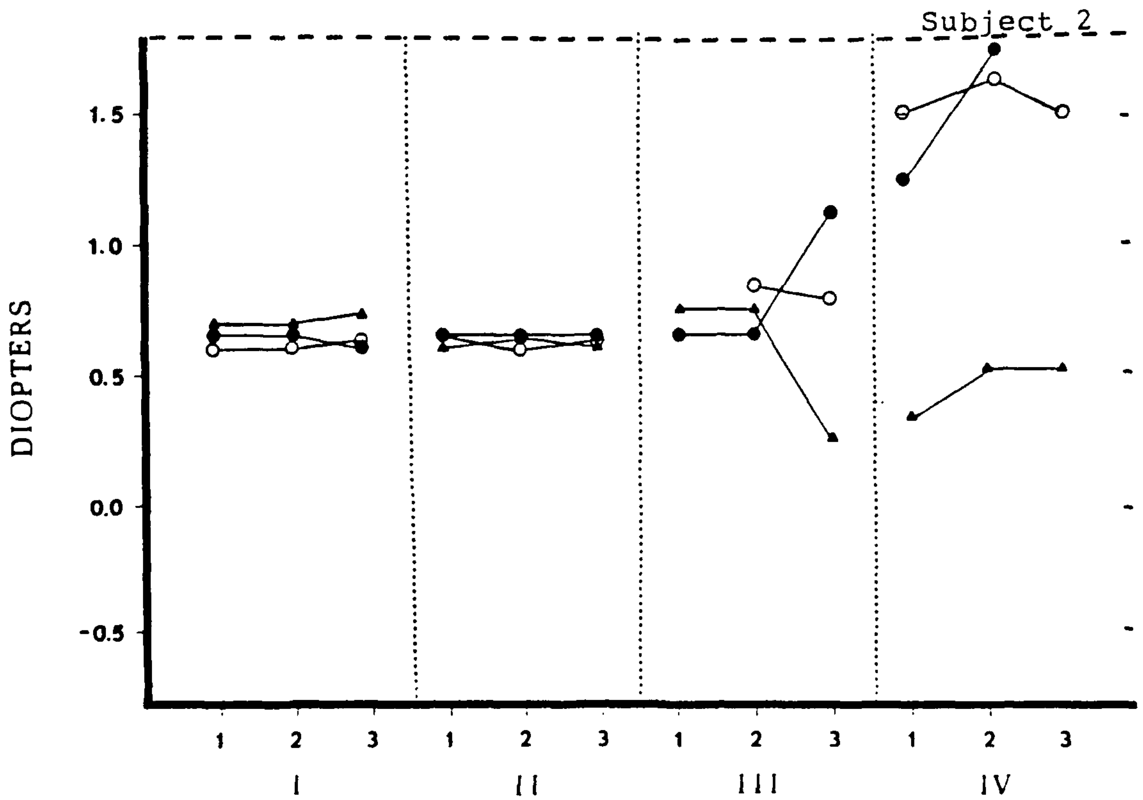
* Not usable as measured - Missing data replaced with cell mean

** Not measured - Missing data replaced with cell mean

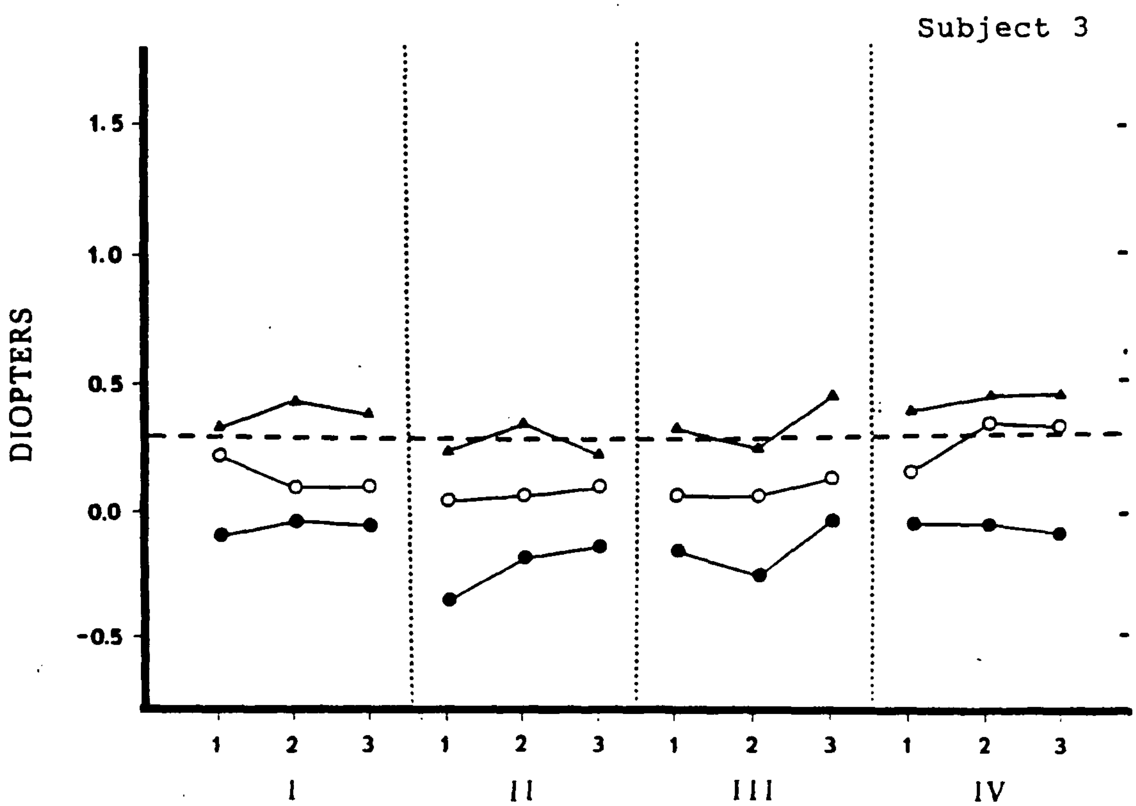
APPENDIX B

GRAPHIC REPRESENTATIONS OF DIOPTIC VALUES ACHIEVED FOR INDIVIDUAL PARTICIPANTS IN EXPERIMENT ONE





LIGHT LEVELS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0.0
-0.5
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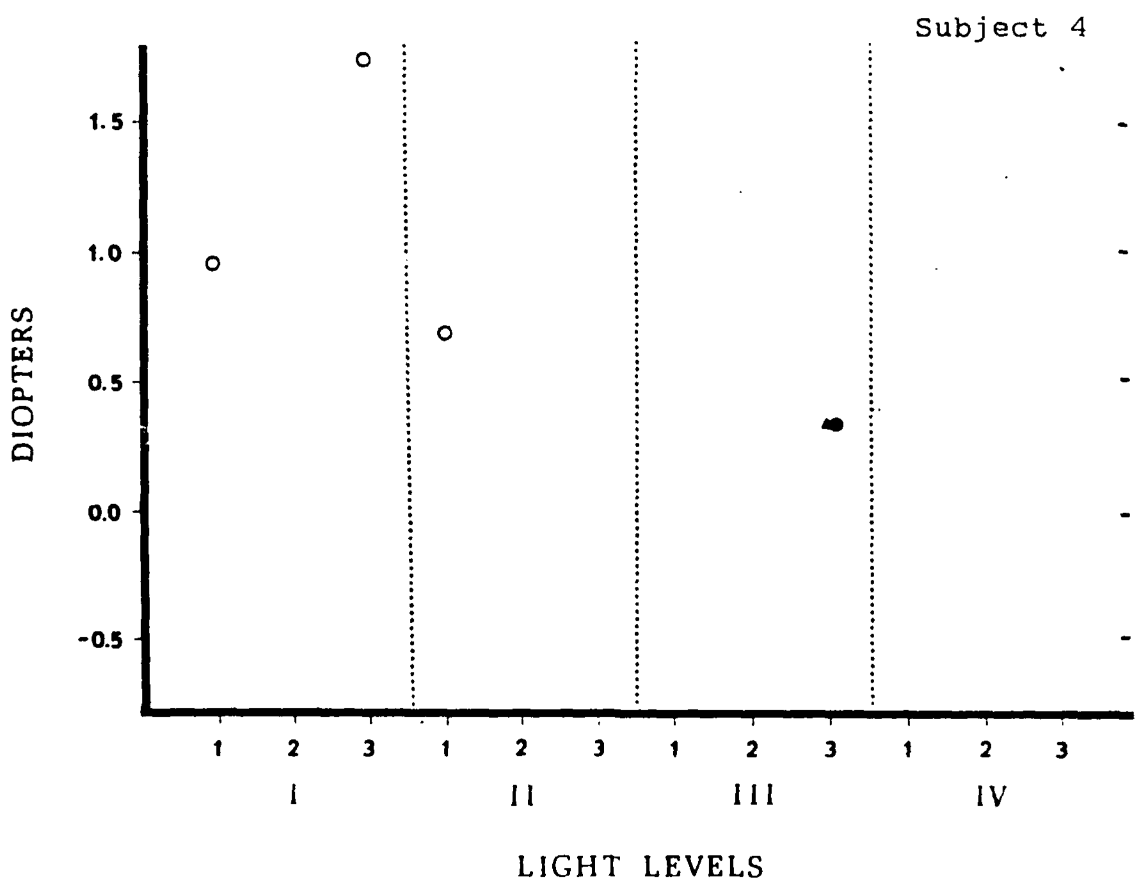
I II III IV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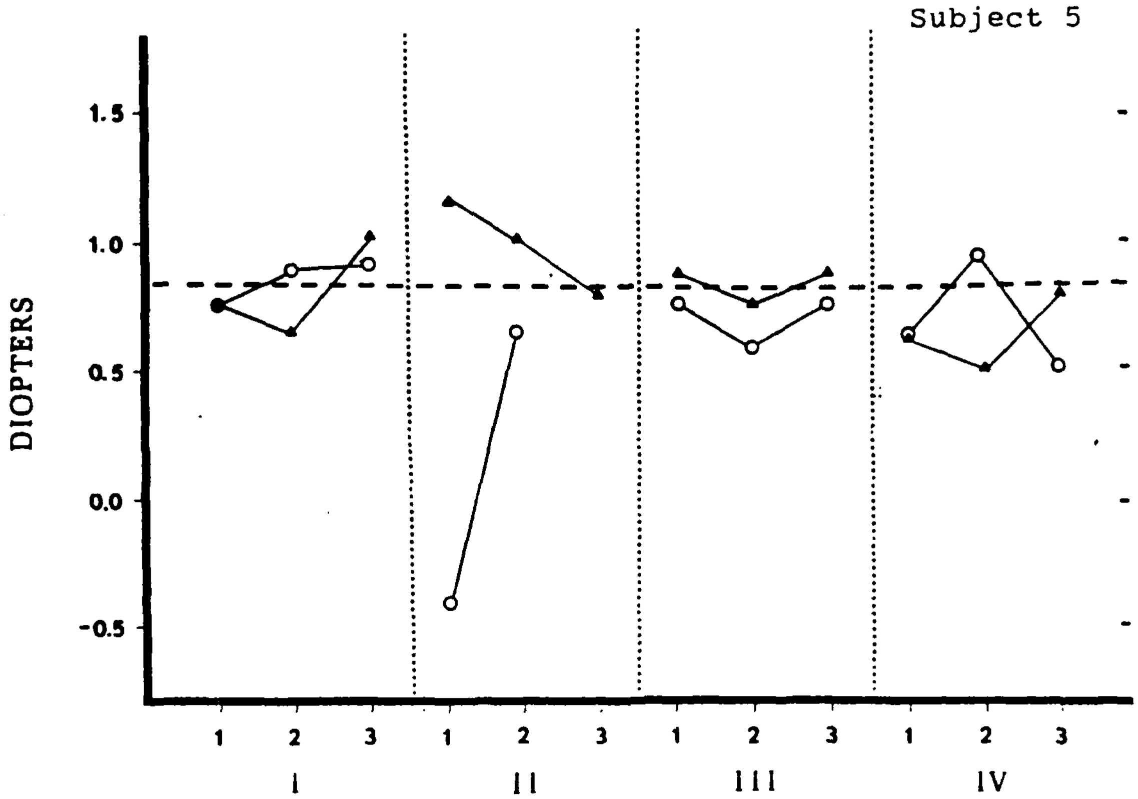
I II III IV
LIGHT LEVELS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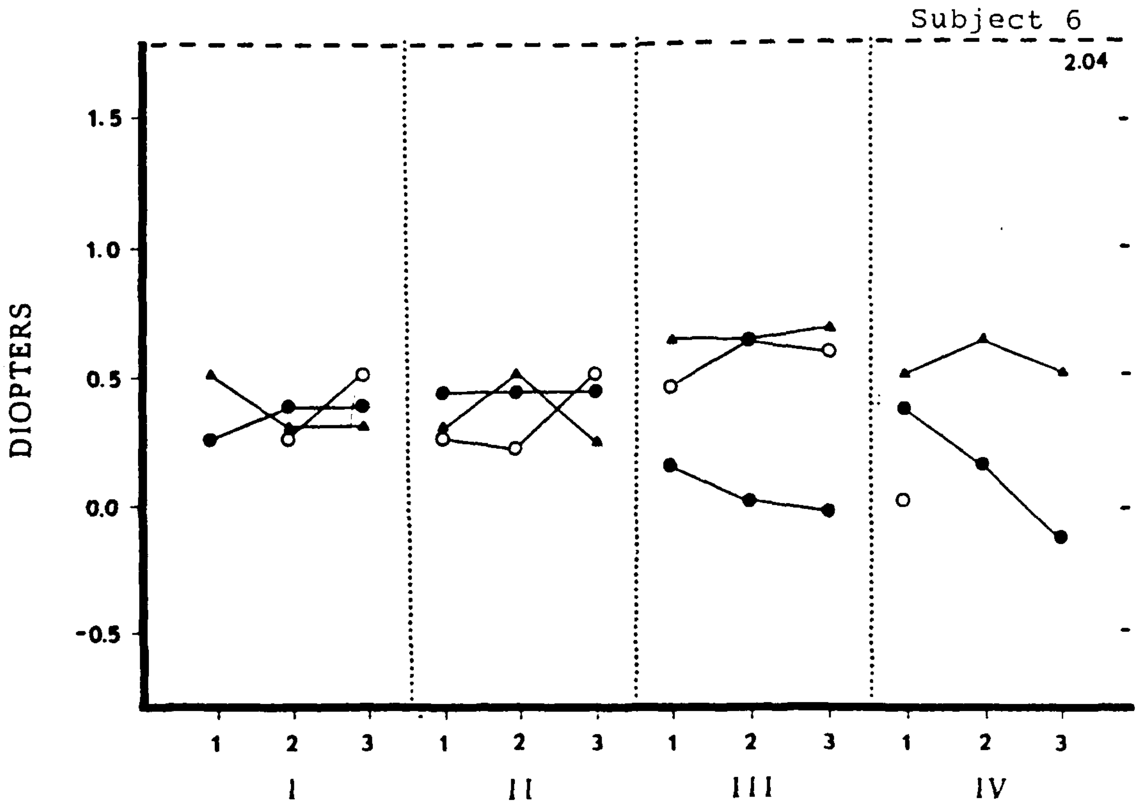
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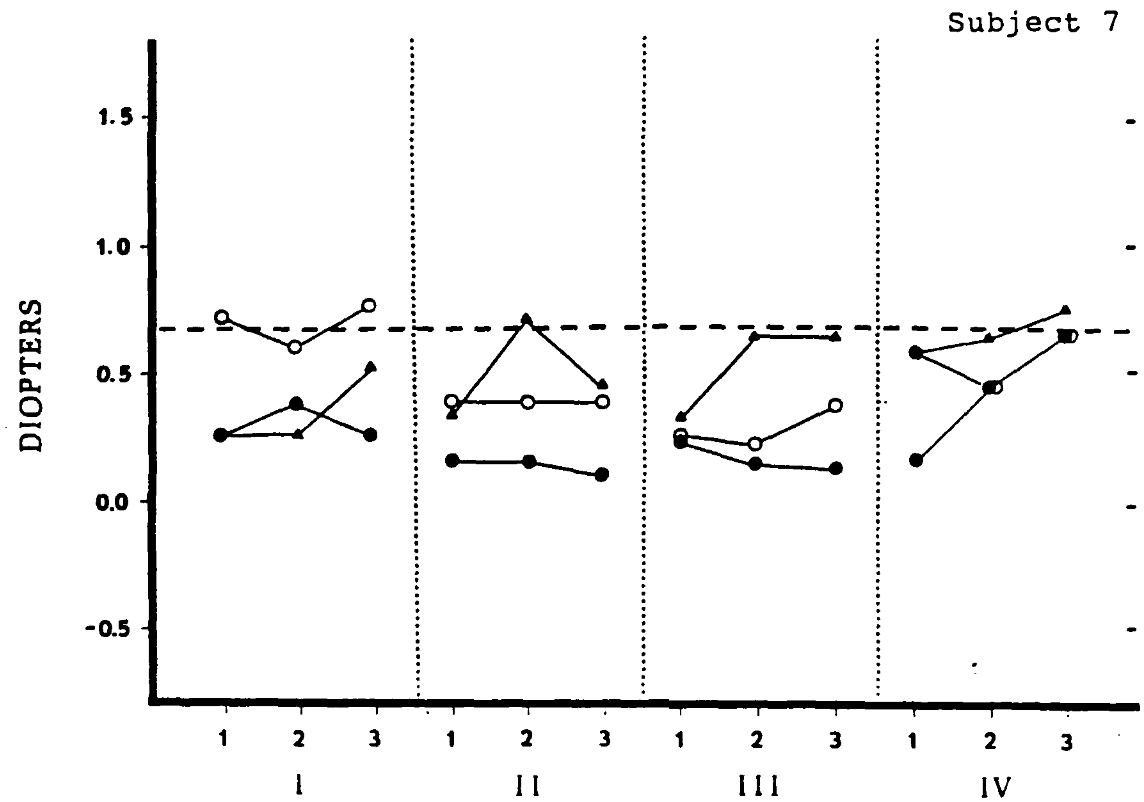
I II III IV
LIGHT LEVELS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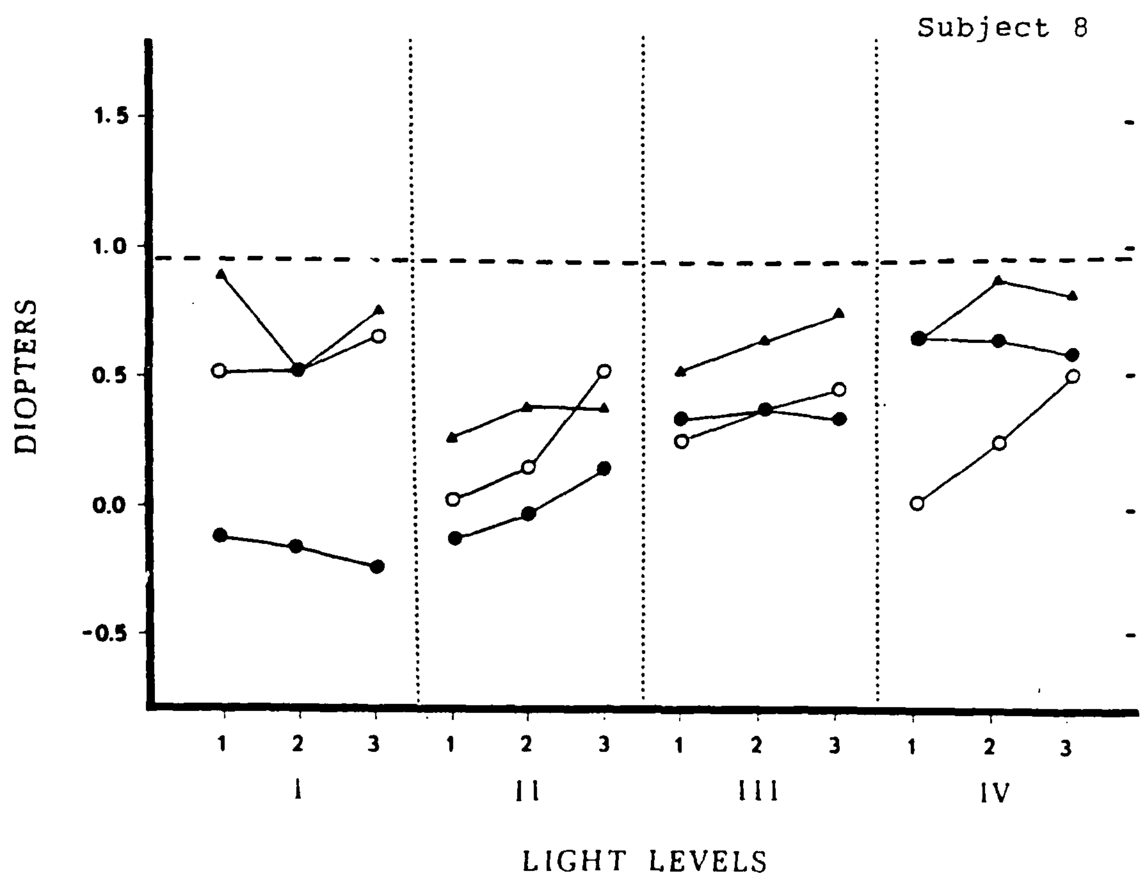
I
II
III
IV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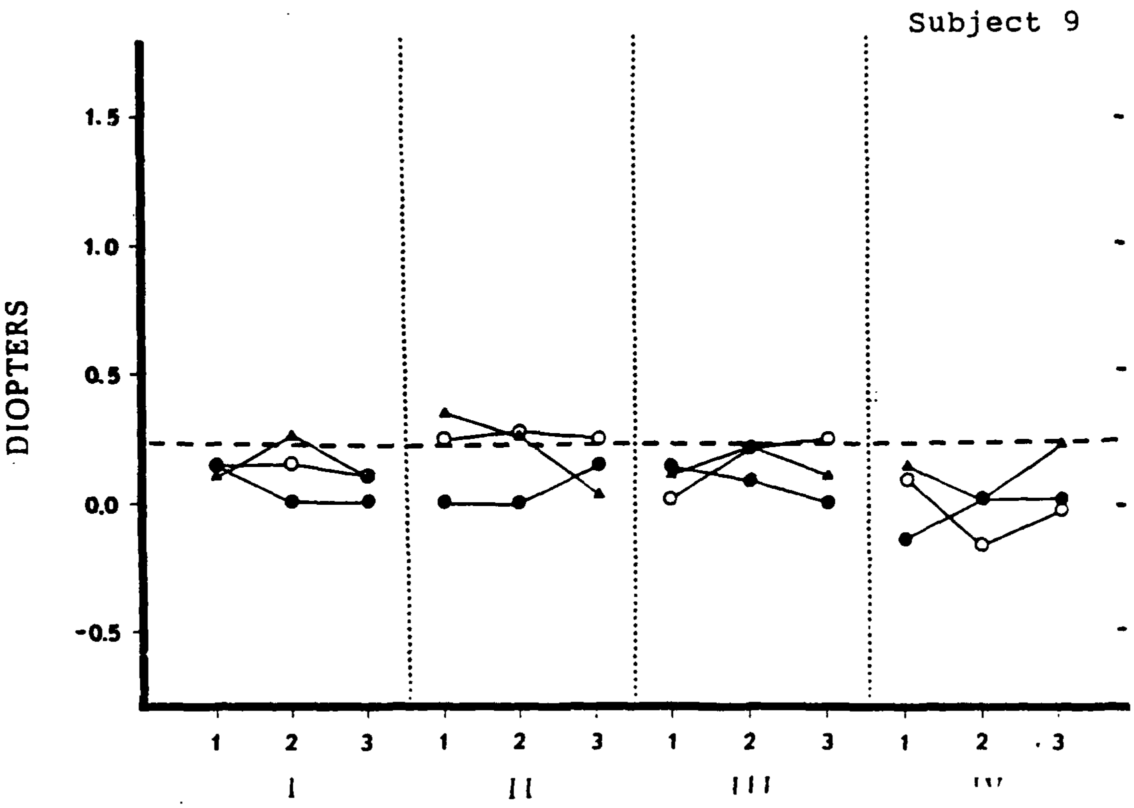
III
IV
LIGHT LEVELS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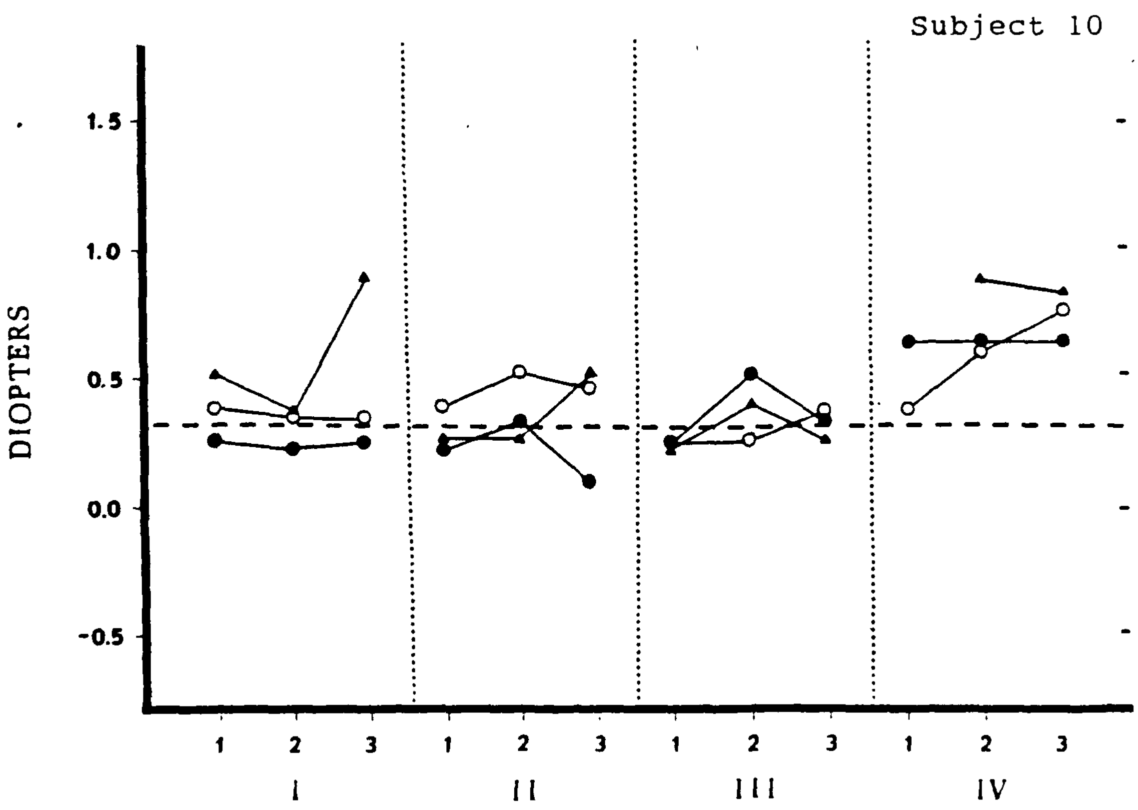
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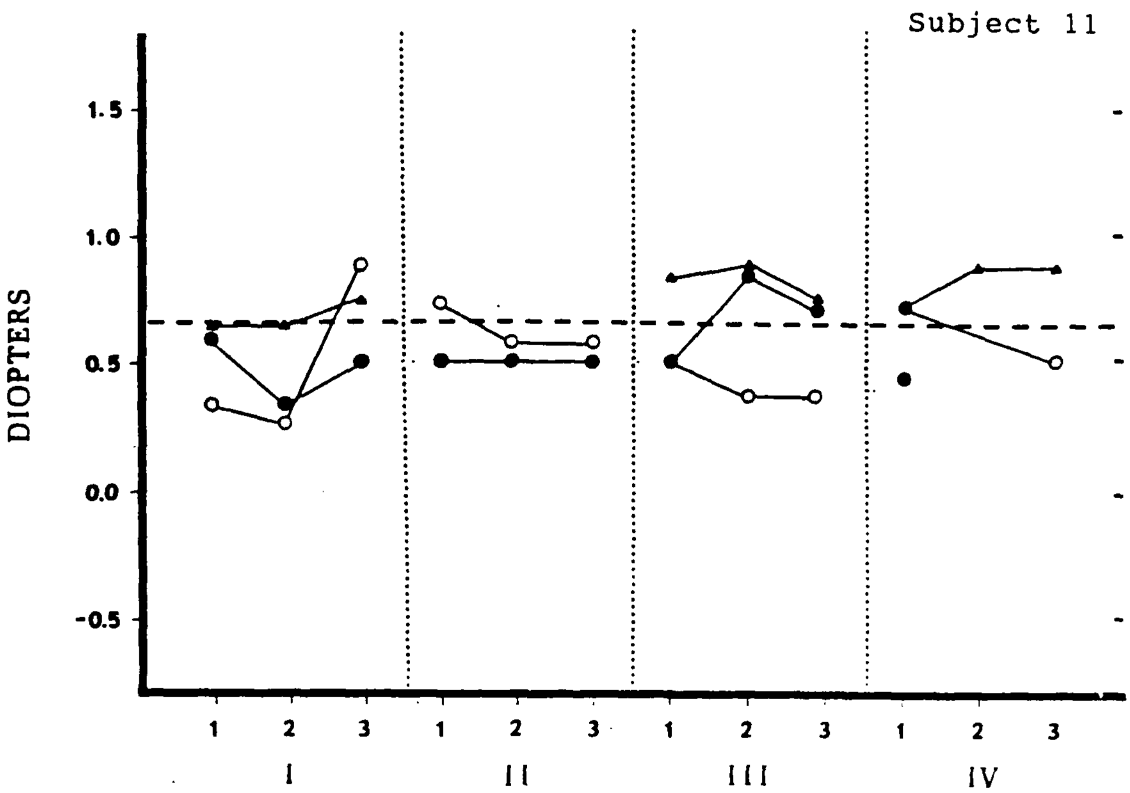
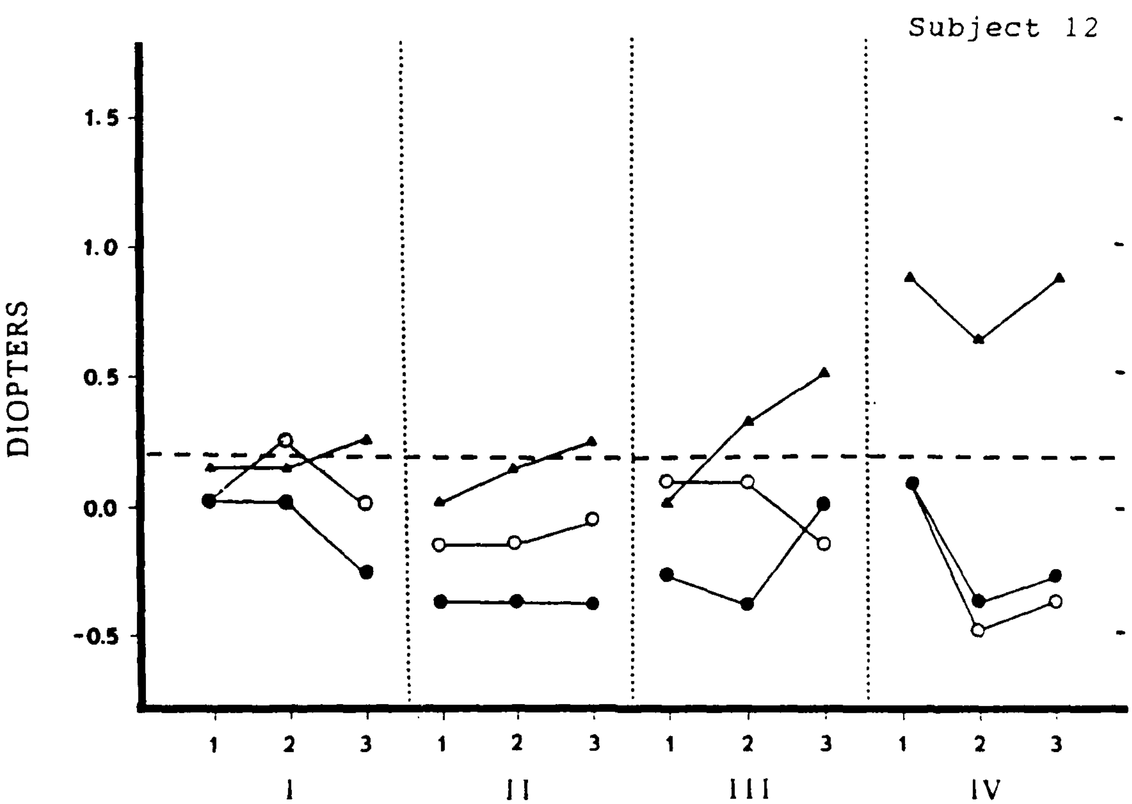
I II III IV
LIGHT LEVELS





LIGHT LEVELS

APPENDIX C

SUMMARY OF DATA AND LOGIC USED TO ESTIMATE INDIVIDUAL RESTING POINT ACCOMMODATION

SUBJECTS

	1	2	3	4	5	6	7	8	9	10	11	12
1.	1.47	1.47	0.22	0.02	0.97	N/O	---	0.97	N/U	0.22	---	0.60
2.	1.47	1.97	0.27	0.85	0.72	2.10	---	1.22	N/U	0.47	---	-0.03
3.	1.60	1.97	0.47	0.72	0.66	1.97	---	0.72	N/U	0.15	---	0.02
4.	1.40	N/U	0.42	-0.23	0.60	1.02*	0.65	N/U	0.22	0.40	0.77	2.47*
5.	1.40	N/U	0.25	N/U	N/U	0.65**	0.72	0.15*	0.15	0.47	0.65	0.77**
6.	1.52	-0.03*	0.22	N/U	1.32	0.45**	0.65	0.52**	0.35	0.35	0.60	0.52**
X	1.48	1.80	0.31	0.53	0.85	2.04	0.67	0.97	0.24	0.34	0.67	0.20

Individual dark focus RPA estimates were calculated as mean values of acceptable evaluations. Specific estimates were omitted as a result of the following reasons:

N/U Response to evalution was not useable

* Response to evaluation was unacceptably deviant from other estimates (i.e., by more than 0.75 diopter)

** Response to evaluation demonstrated an apparent influence from the experimental environment (i.e., shifted toward 0.5 diopter of accommodation.

APPENDIX D

RESPONSE TIMES ACHIEVED FOR THE VISUAL PERFORMANCE TASK IN EXPERIMENT ONE

SUBJECT	SESSION	TRIAL I		II		III		IV		
1	RED	10	9.6	X	X	10	X	10	10	9.92
	GREEN	10	X	10	X	0.8	X	10	10	8.16
	WHITE	3.0	0.9	1.4	4.6	1.1	X	10	10	4.43
2	GREEN	10	X	X	10	10	10	X	10	10.00
	WHITE	10	10	10	10	X	9.1	10	10	9.87
	RED	10	X	1.5	X	1.6	3.2	1.9	10	4.70
3	WHITE	X	10	X	0.8	10	X	X	10	7.70
	RED	7.8	5.6	10	X	10	9.8	X	10	8.87
	GREEN	X	2.6	10	X	1.3	10	10	X	6.78
4	RED	X	X	X	10	10	X	10	10	10.00
	GREEN	X	X	M	X	X	10	X	10	10.00
	WHITE	10	10	10	10	10	X	10	10	10.00
5	GREEN	X	X	10	0.7	10	6.1	X	X	6.70
	WHITE	X	7.1	7.3	X	10	10	0.5	10	7.48
	RED	5.1	10	10	X	10	3.3	10	10	8.34
6	WHITE	10	X	1.4	10	10	X	10	10	8.57
	RED	10	2.2	X	X	3.2	X	10	X	6.35
	GREEN	4.9	0.9	2.8	X	2.1	X	7.3	10	4.67
7	RED	5.2	8.2	2.0	9.5	X	0.8	10	10	6.53
	GREEN	X	2.4	X	3.3	3.6	3.1	X	10	4.48
	WHITE	X	X	2.4	X	X	3.1	10	10	6.38
8	GREEN	8.8	X	X	M	X	3.5	10	X	7.43
	WHITE	6.9	1.0	X	1.8	X	1.5	X	10	4.24
	RED	X	10	X	X	3.6	2.2	X	10	6.45
9	WHITE	10	10	X	10	2.4	X	10	10	8.73
	RED	X	X	10	X	3.5	10	10	10	8.70
	GREEN	X	X	10	10	X	X	10	10	10.00
10	RED	10	4.1	0.1	0.1	1.8	3.7	10	10	4.98
	GREEN	X	2.7	X	X	X	3.9	10	X	5.53
	WHITE	X	5.5	X	X	3.9	2.4	3.2	10	5.00
11	GREEN	X	4.5	1.5	8.3	2.4	X	10	X	5.34
	WHITE	6.7	8.7	7.8	X	X	X	10	10	8.64
	RED	X	2.3	X	M	1.7	5.7	X	10	4.93
12	WHITE	10	X	10	X	9.3	10	10	10	9.88
	RED	1.3	X	10	10	4.6	X	X	X	6.48
	GREEN	10	X	10	10	X	10	X	10	10.00

APPENDIX E

DIOPTER VALUES ACHIEVED FROM EVALUATIONS CONDUCTED IN EXPERIMENT TWO

SUBJECTS

	1	2	3	4	5	6
RED	.60 .57 .65	.22 .25 .27	.15 .27 .27	.82 1.25 1.27	.15 -.11 .27	.35 .27 .35
GREEN	.62 .65 .85	.05 .10 .07	.10 .22 .22	1.27 .77 .77	.27 .02 .02	.10 .27 .02
WHITE	.40 .40 .62	.10 .15 .15	.27 .22 .22	.77 .97 1.02	.15 .02 .15	.22 .15 .27
RED	.47 .27 .47	.15 .02 .22	.10 .15 .10	1.10 .97 .52	.35 .02 .22	.15 .22 .15
GREEN	.65 .72 .90	.02 -.03 -.06	.10 .02 .10	1.27 1.27 1.35	.10 .35 .22	.52 .35 .40
WHITE	.35 .65 .60	.10 -.03 -.01	.16** .22 .10	1.06* .90 1.22	.27 .72 .10	.22 .10 .22

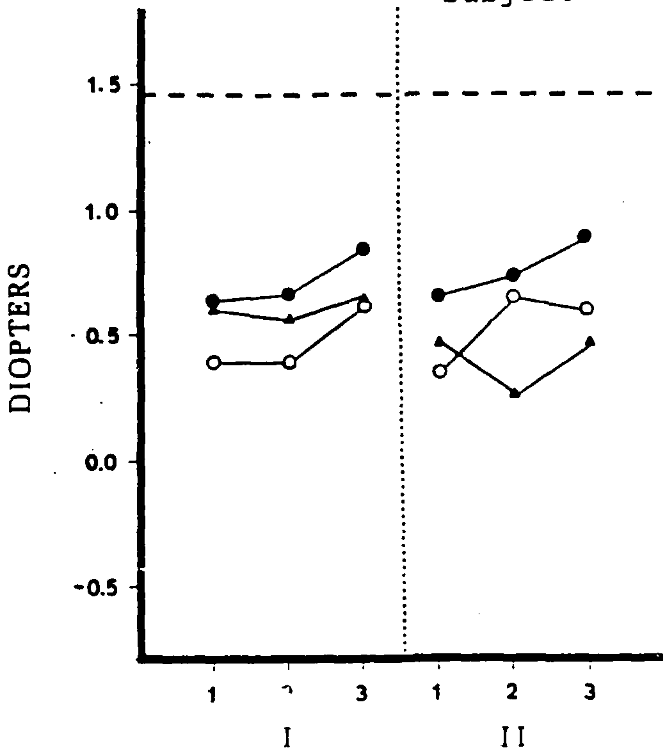
* Not usable as measured - Missing data replaced with cell mean

** Not measured - Missing data replaced with cell mean

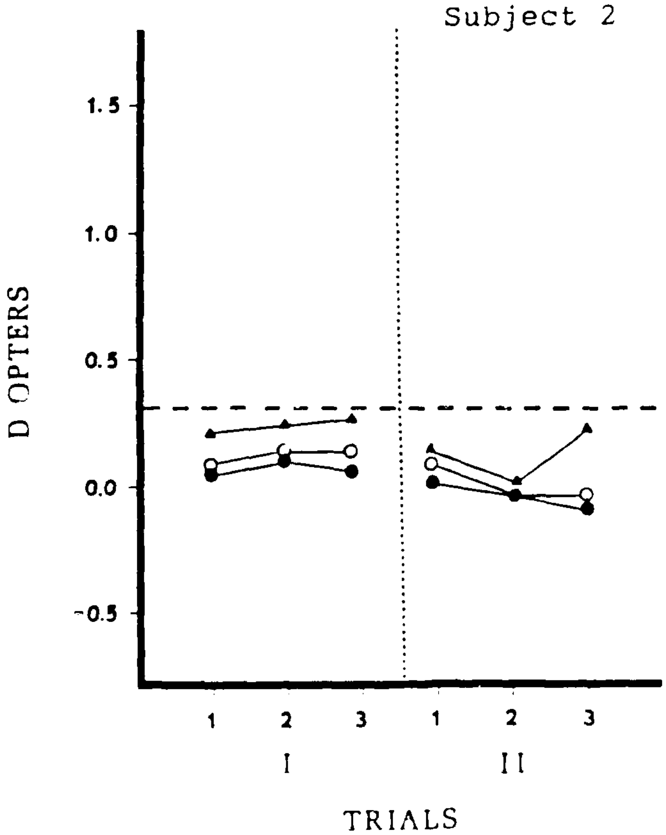
APPENDIX F

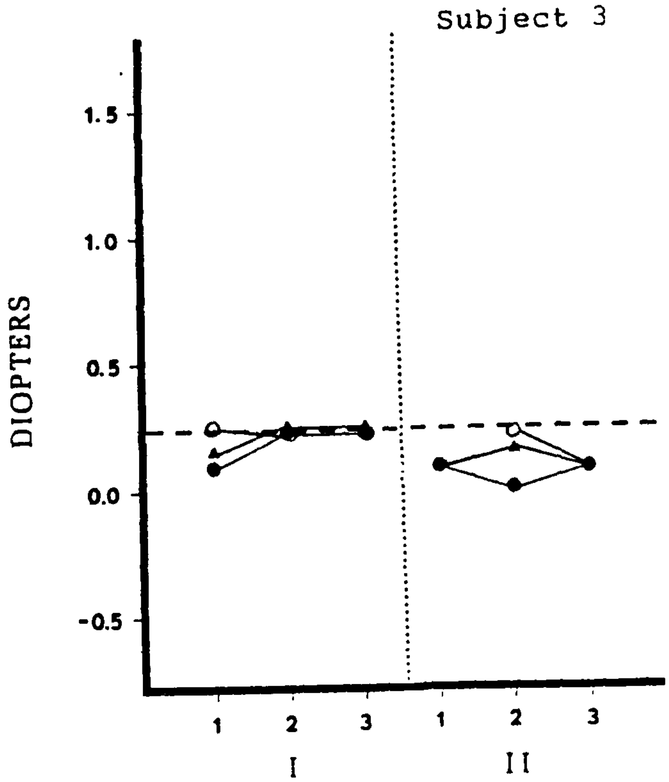
GRAPHIC REPRESENTATIONS OF DIOPTER VALUES ACHIEVED FOR INDIVIDUAL PARICIPANTS IN EXPERIMENT TWO

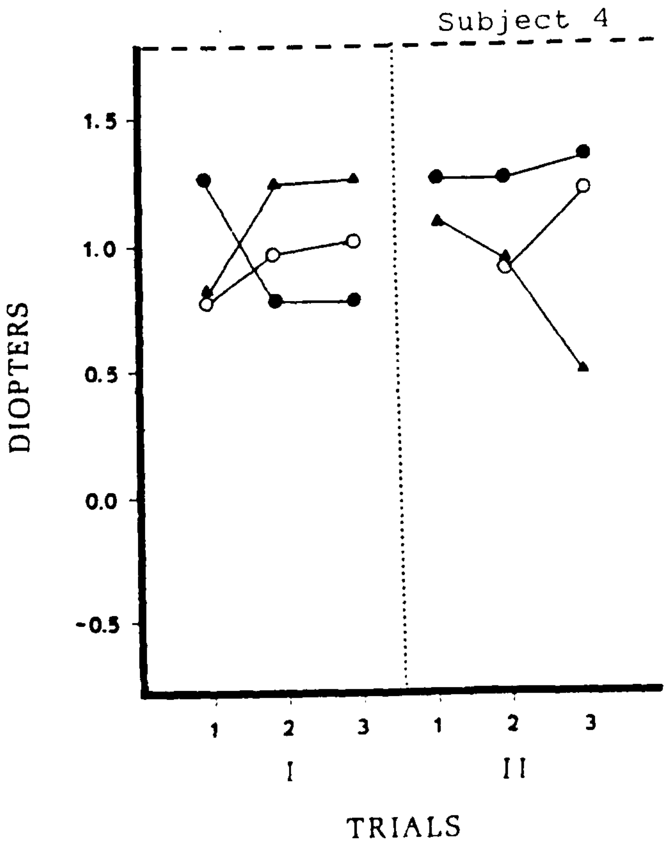
Subject 1



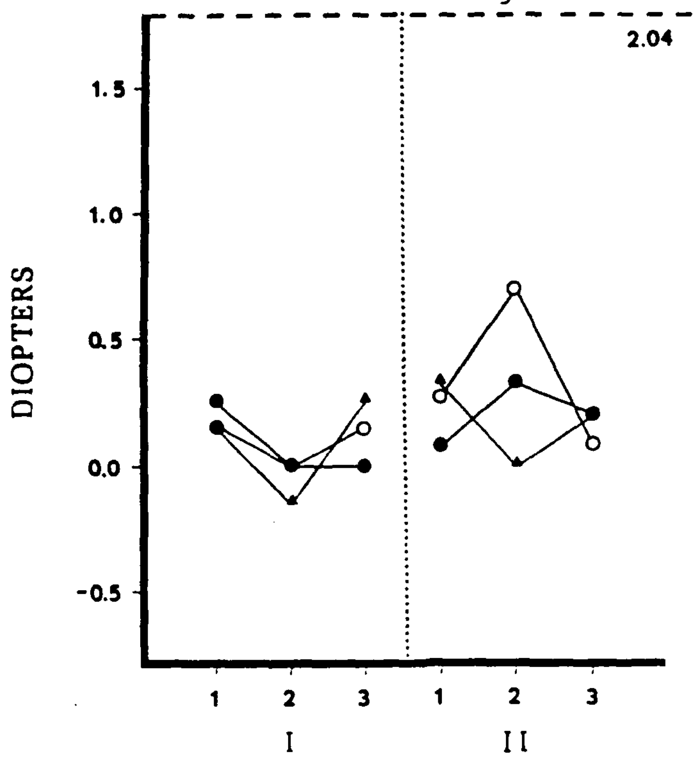
Subject 2



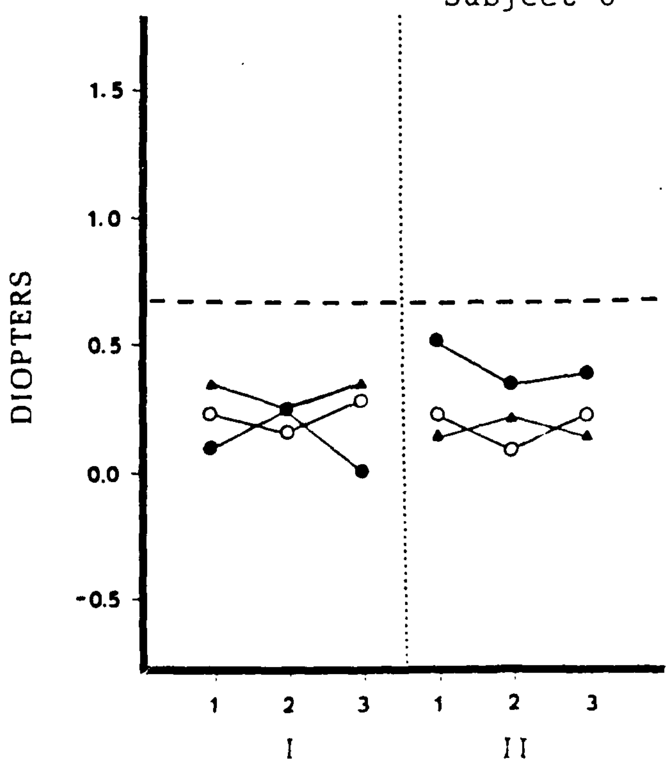

Subject 3
DIOPTERS
1.5
1.0
0.5
0.0
-0.5
1
2
3
1
2
3
I
II


Subject 4
DIOPTERS
1.5
1.0
0.5
0.0
-0.5
1
2
3
1
2
3
I
II
TRIALS

Subject 5



Subject 6



TRIALS

APPENDIX G

RESPONSE TIMES ACHIEVED FOR THE VISUAL PERFORMANCE TASK IN EXPERIMENT TWO

SUBJECT	TRIAL	COLOR	1	2
1	I	RED	X	3.6
		GREEN	X	6.6
		WHITE	X	X
	II	GREEN	9.7	3.6
		WHITE	X	M
		RED	X	3.0
2	I	WHITE	10	10
		RED	10	10
		GREEN	X	M
	II	RED	5.2	10
		GREEN	X	X
		WHITE	1.5	X
3	I	GREEN	X	10
		WHITE	10	M
		RED	10	X
	II	WHITE	X	X
		RED	10	10
		GREEN	X	X
4	I	RED	10	X
		GREEN	10	10
		WHITE	10	X
	II	GREEN	10	X
		WHITE	10	X
		RED	10	10
5	I	WHITE	X	3.1
		RED	X	X
		GREEN	9.4	X
	II	RED	X	M
		GREEN	X	0.7
		WHITE	3.1	X
6	I	GREEN	4.5	9.2
		WHITE	4.7	X
		RED	3.3	X
	II	WHITE	1.7	0.2
		RED	7.4	0.8
		GREEN	0.9	X

X = Visual performance task not administered.

M = Missing data.

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